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PHYSICAL MEMOIRS.

RADIANT ELECTRODE MATTER

AND THE SO-CALLED

FOURTH STATE.

BY

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Preface.

THE interest aroused by my vacuum apparatus, when exhibited in the Paris International Electrical Exhibition of 1881, not only in my colleagues, but also in lovers of natural science, seemed to show that the publication of a comprehensive account of the investigations thereon would be acceptable; it has been published in four papers in the Memoirs of the Imperial Academy of Vienna. In the present complete edition many parts have been abridged and others extended and corrected in the light of the results of later investigations. A communication is added as appendix :— "Contribution to the explanation of Zöllner's Radiometer," whose simple phenomena of motion may assist in the easier comprehension of the, for the most part complicated, motions of electrical radiometers.

All the vacuum apparatus described here I have con-

structed in the physical laboratory of the Vienna University, and some is now in the Conservatoire National des Arts et Métiers, in Paris. The firm of Messrs. F. O. R. Goetze, of Leipsic, have undertaken the construction of the apparatus, and I gladly take this opportunity of testifying that the samples sent me have been constructed with great skill and knowledge of the subject.

Is there a Fourth State of Aggregation of Matter?

> Causas rerum naturalium non plures admitti debere, quam quae et verae sint et earum phaenomenis explicandis sufficiant (*Princ.* I. iii.).—NEWTON.

AMONG physicists the view has for long been held that investigations on electrical discharges in rarefied gases will lead to a knowledge of the nature of electricity. To this circumstance we owe a copious literature, of which I will here only mention the beautiful investigations of W. Hittorf*, which he published in the year 1869, in two papers entitled "On the Conduction of Electricity in Gases," and which have been taken little account of even by colleagues, perhaps because the title was somewhat too modest.

Mr. William Crookes, to whom Hittorf's work was apparently unknown, gave in a lecture† to the British Association in Sheffield, on August 22nd, 1879, a review of the results obtained by him, which do not differ substantially from Hittorf's, and are only to be distinguished by a more elegant form of experiment. The conclusions, however, to which these experiments led Mr. Crookes are new, and they aroused general attention and no small interest, especially in

* Poggendorff's *Annalen*, vol. cxxxvi. [*vid. supr.* p. 111].

† This lecture was published in German, entitled "Radiant Matter or the Fourth State. By William Crookes. Translated into German, with the author's sanction, by Dr. Heinrich Gretschel," Leipsic, 1879. The following papers appeared also :—"On the Illumination of Lines of Molecular Pressure and the Trajectory of Molecules," Proc. R. S. vol. xxviii. no. 191; Phil. Mag. 1879, ser. 5, vol. vii. p. 57; 'Nature,' 1879, July 3 and 10.

those circles which delight in occupying themselves with questions of transcendental views of the universe.

To explain the phenomena observed in the exhausted spaces, Mr. Crookes assumes that the very rarefied residual gas exists in a new "ultragaseous" state, which he calls the "fourth state," and designates by an expression borrowed from Faraday, "radiant matter."

The assumption of the fourth state is justified by Mr. Crookes in the following manner * :—

"The further this process (the rarefaction) is carried the longer becomes the average distance a molecule can travel before entering into collision; or, in other words, the longer its mean free path the more the physical properties of the gas or air are modified. Thus, at a certain point, the phenomena of the radiometer become possible, and on pushing the rarefaction still further, *i. e.* decreasing the number of molecules in a given space and lengthening their mean free path, the experimental results are obtainable to which I am now about to call your attention. So distinct are these phenomena from anything which occurs in air or gas at the ordinary tension, that we are led to assume that we are here brought face to face with matter in a fourth state or condition, a condition as far removed from the state of gas as a gas is from a liquid."

There are, accordingly, two reasons which point to the need of the assumption of a fourth state:—1. The high degree of rarefaction. 2. The difference of the phenomena from those which take place under ordinary pressure.

We will submit these reasons to a discussion in order to ascertain what probability is to be assigned to the hypothesis assumed.

The three states of aggregation of bodies hitherto known depend upon the difference in the mobility of their smallest particles as well as on the different conditions of cohesion. In the gaseous state the particles attain the highest degree of mobility and the cohesion is infinitely small. What now characterizes this hypothetical fourth state? Is it perhaps a still greater mobility of the particles and a still smaller degree of cohesion? This is scarcely admissible so long as molecules and atoms exist as such. This question, too, is not left un-

* 'Nature,' 1879, p. 419.

answered in the publication in question. It is there said * :—"In studying this fourth state of matter we seem at length to have within our grasp and obedient to our control the little indivisible particles which with good warrant are supposed to constitute the physical basis of the universe. We have seen that in some of its properties radiant matter is as material as this table, whilst in other properties it almost assumes the character of radiant energy. We have actually touched the borderland where matter and force seem to merge into one another, the shadowy realm between known and unknown, which for me has had always peculiar temptations. I venture to think that the greatest scientific problems of the future will find their solution in this borderland and even beyond; here, it seems to me, lie ultimate realities."

Radiant matter would thus consist of very small indivisible particles, the ultimate atoms, into which the residual gas and any ponderable matter resolves itself at the highest degree of rarefaction, which is stated to be at a millionth of an atmosphere.

Ponderable bodies can be decomposed by forces we are acquainted with into simpler substances known as elements. The chemist Prout, and after him the celebrated Dumas have established the fact that a certain regularity exists between the atomic weights of simple substances according to which all simple bodies have an atomic weight, which is equal to a multiple of the atomic weight of a still unknown body whose equivalent is only half the equivalent of hydrogen. Moreover Dumas, guided by the analogy of the compounds which are formed by organic radicals, came to the conclusion that the equivalents of simple substances which belong to one and the same natural family form an arithmetical series in the same way as the radicals of organic chemistry. These facts point with great probability to the assumption that the bodies which we regard as simple substances are compounds of a higher order, that they are very complicated aggregates of other elements which themselves are compounded, but that finally they can all be decomposed into one single matter. The decomposibility and invariability of chemical elements has especially in recent times been assumed and established

* 'Nature,' 1879, p. 439.

in various ways by investigators, such as Mendeleeff, Lothar Meyer, Norman Lockyer, Gorup Besanez, Fr. Wächter, and others.

The assumption of the unity of matter, which from a philosophical point of view is self-evident, finds support also in comparative spectrum analysis. Cimician's investigations in this direction show that on the basis of Mendeleeff's series and the *homology* of spectra it would be possible to reduce all the elements of the chemistry of to-day to the typical elements hydrogen, lithium, beryllium, boron, carbon, nitrogen, oxygen, and fluorine. All other elements are formed from those mentioned, by the addition of oxygen in different forms of condensation. But some of these typical elements too, carbon, boron, and beryllium, as well as magnesium, possess homologous spectra, and must therefore be compound bodies. Whether the rest of the elements—hydrogen, lithium, nitrogen, oxygen, and fluorine—are to be considered as the ultimate constituents can scarcely, according to Cimician's views, be determined by spectroscopic means.

Matter is accordingly capable of a further divisibility, and it is possible that in its ultimate division it would give that so-called imponderable matter which we call æther and which reveals its existence by the mode of motion of radiation, and whose material character and inertia is proved in that it exchanges its motion with ponderable matter.

We will now consider the methods which we can employ to decompose bodies. These are reducible to the molecular work which heat, electricity, and chemical force can perform. Very complicated molecules like those of organic substances can be decomposed even at moderate temperatures; on the other hand simple substances, even when exposed to temperatures above 1500° C., remain undecomposed. Like the energy of heat, so also the energy of the strongest electrical currents and that of chemical affinity have proved too weak to resolve the bond of the ultimate atoms into the atoms of the elements. If we had those smallest particles which form the "physical basis of the universe," they must certainly be of quite a different nature to our elements, so that the name "state" would not even be applicable, they might possibly be identical with the particles of æther. This, however, is not

the case, since the molecules of radiant matter preserve their *characteristic chemical* properties, as Mr. Crookes himself has experimentally shown. Moreover, that the observed phenomena of phosphorescence, of shadow, of magnetic deflection, and also the phenomena of motion commence in different gases at different pressures is in accordance with the conclusions which follow from the kinetic theory of gases, and show that in rarefied gases we have still to do with *actual* molecules ; the metallic deposit in the region of the negative electrode also favours this view.

Experiments, too, with the plate of quartz, which will be more minutely described afterwards, have shown that we have here not to do with the radiation of æther matter but with the movement of gaseous particles (p. 250, *postea*).

Mr. Crookes believes he has attained the ultimate division of matter by means of a high degree of rarefaction, stated to be at a pressure of a millionth of an atmosphere, 0·00076 mm. Mr. Crookes, when he was led to this assumption, may perhaps have had present to him the idea that a liquid body passes more easily into the gaseous state the smaller the cohesion which keeps the particles together and the less the external pressure which acts on the particles, and that also dissociation of complicated molecules takes place much more easily at a reduced pressure. It must, however, on the other hand, be mentioned that that part of the energy of molecular motion which overcomes the pressure is relatively small compared with that part which in evaporation must overcome cohesion, and in dissociation chemical affinity, but which is certainly infinitely small compared with that part which is necessary to tear asunder the bonds of the primitive atoms.

Moreover, no such high degree of rarefaction is necessary for the phenomena of radiant matter as Mr. Crookes has obtained, for direct manometer measurements showed that even under a pressure of 0·01 mm. of mercury a current of moderate intensity (with a spark 2 cm. long) no longer passes through the tube. I am firmly convinced that even with a rarefaction of a trillionth, from the computation of the kinetic theory of gases, we should still have about 21 *molecules* in a cubic centimetre of air, and that a decomposition of the same into the ultimate atoms is not to be expected until another,

more powerful source of energy has been discovered than the ones known up to the present time.

If the supposition were correct that gaseous matter can be converted by rarefaction into the fourth state, then the heavenly bodies which hover in a better vacuum than we can ever obtain must resolve themselves by degrees into ultimate matter.

Still less can I recognize the necessity for a new state because these phenomena are "different" from everything which has been observed at ordinary pressures. The necessity of any new supposition would only then be proved if the phenomena could not be explained by what we know at present.

On these grounds I cannot decide to adhere to the existence of the fourth state, and incline just as little to the view that we are here touching the borderland "where matter and force seem to merge into one another;" but least of all that we have here an open door into the world of four dimensions, as many transcendental thinkers find credible.

How matter and force can merge into each other is a secret which Mr. Crookes has omitted to explain.

The Dark Space in the Glow-light.

In an ordinary Geissler's tube filled with air at a pressure of about 0·5 mm. a red brush of light is seen at the positive pole, which, consisting of light and dark strata, fills the greater part of the tube—at the negative pole a blue light, the so-called glow-light, and between the two a dark space, to the explanation of which I shall subsequently refer. On continuing the rarefaction the strata of positive light disappear gradually, and the glow-light, which is always separated from it by the dark space, spreads over the whole length of the tube. On more carefully examining the glow-light a second relatively dark space can be quite clearly distinguished at the electrode, which is sharply defined from the first by a broad band of glow-light of decreasing intensity. The electrode itself is very often covered with a yellow, dust-like layer. which has the appearance of gold dust, and is a phenomenon of phosphorescence of the furthest layer of oxide.

This dark space, which has long been known and which is

very accurately described by Prof. Hittorf, Mr. Crookes considers to be the "mean free path of the gaseous residue." The reasoning for this supposition may follow here and speak for itself.

"This* dark space is found to increase and diminish as the vacuum is varied, in the same way that the mean free path of the molecules lengthens and contracts. As the one is perceived by the mind's eye to get greater, so the other is seen by the bodily eye to increase in size ; and if the vacuum is insufficient to permit much play of the molecules before they enter into collision the passage of electricity shows that the 'dark space' has shrunk to small dimensions. We naturally infer that the dark space is the mean free path of the molecules of the residual gas, an inference confirmed by experiment."

The reasoning of Mr. Crookes is therefore: A and B change in the same manner if C changes, therefore A must *equal* B. Reasoning in this way we could, for example, find that the pressure in a certain volume of gas is equal to the number of molecules present, because both decrease in the same way as the mean free path. The fallacy is too apparent, and it helps us little that Mr. Crookes, by means of induction-sparks "actually illuminates the lines of molecular pressure." The dark space is no mean free path, and only a phenomenon *dependent* on it, as we shall easily understand after we have recognized the nature of radiant matter.

It is sufficient to make a few experiments with electrodes of different metals—platinum, copper, silver, zinc—to obtain an insight into the processes in the dark space. By using an induced current, giving a spark of about 6 cm., the glass sides even in the course of half-an-hour are covered with a mirror of the corresponding metal. The metallic coating is strongest near the kathode, and extends as far as the glow-light.

If the tube near the negative pole is placed between the limbs of a horseshoe magnet the glow-light contracts near the electrode, and a smaller portion of the glass tube becomes coated with metal. By putting glass plates opposite

* Nature,' 1879, p. 419.

plate-shaped platinum electrodes, I obtained in this way beautiful platinum mirrors.

Aluminum is the only metal I know which gives no appreciable mirror on glass, and is therefore called "non-volatile." The slight deposit which the glass also shows on the use of this metal, and which can only be detected by the phenomena of phosphorescence, to be examined later, might arise from other metals from which the aluminum had not been completely purified.

I am inclined to look for an explanation of the reason that the aluminum particles do not stick to the glass either in their chemical constitution or in their properties of adhesion. But particles of aluminum also are torn off and transported, and move until there is an opportunity of sticking to a place on the positive or negative electrode. There can accordingly be no doubt that individual particles of the electrodes become mechanically detached by the electrical current, not by evaporation, and are shot out perpendicularly to the surface of the electrode, and with a relatively very great velocity. The particles are charged with statical negative electricity, and themselves moving away they transport the latter *convectively*, and in this way keep up the conduction between both electrodes. That particles of gas also partake in this electrical convection is a matter of course. By this stream of particles the gas is forced away from the electrodes just in the same manner as in a gas-flame the issuing gas forces the particles of air before it and forms the dark space close to the orifice into which very few molecules of oxygen can penetrate, and which is the greater the greater the velocity with which the gas issues. At the boundary where the particles of the electrodes clash with the molecules of gas, the former are diverted into all possible directions from their original rectilinear progressive motion by impacts of the latter in all directions. A mutual diffusion of particles of the electrodes and of gas takes place, accompanied by a deposition of the former on the glass walls. As the pressure must be equal in all parts of the tube their number in the unit of volume must be smaller, and therefore that space in which particles of the electrodes have not yet mixed with molecules of gas appears relatively dark. The agitation of the material

molecules with their envelopes of æther at the boundary where the particles of the electrodes and gas meet will be violent, since one part of the progressive motion of radiant electrode matter becomes changed into atomic motion and motion of the envelopes of æther; hence the phenomena of heat and phosphorescence must be gradually more intense there, and gradually decrease with the distance from the electrodes.

The particles thus move in straight lines through the dark space, and the boundary where they collide with the particles of gas and with one another is distinguished by its great brightness. Outside this bright boundary the particles of gas and of the electrodes move in all possible directions, and in proportion as the particles of gas preponderate in number the intensity of the *glow-light* decreases. I designate by this latter name the mixture of the particles of the electrodes and of gas which lies between the dark space on the electrode and the dark space next following.

As the particles of the electrodes and of gas of the glow-light must be at the same temperature, we must have

$$\mathrm{MU}^2 = mu^2,$$

if M, U, m, u express the mass and velocity of a particle of the electrode and of gas respectively. Since it is very probable that the particles of the electrodes are of different sizes, often large lumps, M shall be taken to represent the mass of a particle of mean magnitude. We thus obtain for the velocity of a particle of the electrode

$$\mathrm{U} = \sqrt{\frac{m}{\mathrm{M}}}u,$$

a magnitude which will be smaller than the molecular velocity of the particles of gas, since in most cases M will be greater than m.

In the bright *bounding layer* of the dark space the number of particles of gas will be very small, and therefore, considering them as particles of the electrodes, we can assume that in the unit of volume there are N particles of the electrodes which move about in *all* directions. In the dark space there are N_0 particles in the unit of volume, which, however, move towards the bright layer *only* in *one* direction. Hence

the pressure on the unit of surface of the bright layer of the glow-light which the progressive molecules of the dark space exert is

$$p = N_0 M U_0^2$$

where U_0 expresses the velocity of the progressive motion of the particles. On the other hand, the pressure from the opposite side of the bright layer is

$$p = \tfrac{1}{3}\, NMU^2,$$

where U, however, expresses the velocity with which the particles move in all possible directions.

Since the bright layer is in equilibrium we must have

$$N_0 M U_0^2 = \tfrac{1}{3}\, NMU^2;$$

and because we assume equality of temperature we also assume equality of the *vis viva* of a molecule, we find

$$N_0 = \tfrac{1}{3}\, N.$$

The number of molecules in the unit of volume of the dark space is one third that of the bright layer.

The smaller brightness of the relatively dark space depends chiefly on the smaller number of luminous particles of the electrodes, and not, as was assumed by Mr. Crookes, on the deficiency of impacts of the same with particles of gas.

If the particles of the electrodes strike against a fixed platinum plate, almost the whole energy of their progressive motion is converted into heat, and the platinum becomes red hot. On the other hand, in a collision between particles of the electrode and of gas the progressive motion of the former is simply transferred to the latter, and the movable particles cannot therefore be caused to glow. Their luminosity is caused by a discharge of electricity and not by collision, since the *emittent* kathode rays, as also the particles of the electrodes in the dark space in which they relatively infrequently collide, likewise phosphoresce.

As the entire mass of gas is in a stationary condition in the glass tube, the pressure in the dark space is not only equal to the pressure in the glow-light but is also equal to that at another point. We must therefore have

$$p = N_0 M U_0^2 = \tfrac{1}{3}\, nmu^2,$$

if n, m, u refer to gas.

Since the particles of gas move in all directions we shall now have, if the temperatures are equal, which is approximately the case,

$$N_0 = \tfrac{1}{3}n \text{ and } U = \sqrt{\frac{m}{M}}u.$$

The velocity of the particles in the dark space is smaller than the molecular velocity of the gas, and can therefore, so long as the dark space remains visible, amount to several hundred metres.

At a higher degree of rarefaction the electrical tension necessary for discharge, as also the velocity of the particles thrown off, is greater, and as, moreover, the resistance of the residual gas is also less, the dark space increases more and more, and its limits disappear if the rarefaction reaches about 0·03 mm.

Even if the velocity of the electrode particles at a higher rarefaction is somewhat greater than the molecular velocity of the gases, it will never reach the magnitude of 800,000 metres per second deduced by Goldstein under certain assumptions which are by no means justifiable.

Mr. Crookes maintains that the *residual* gas inside the dark space exists in the fourth state, and calls it "radiant matter."

In my opinion *the matter which fills the dark space consists of mechanically detached particles of the electrodes which are charged with statical negative electricity, and move progressively in a straight direction.*

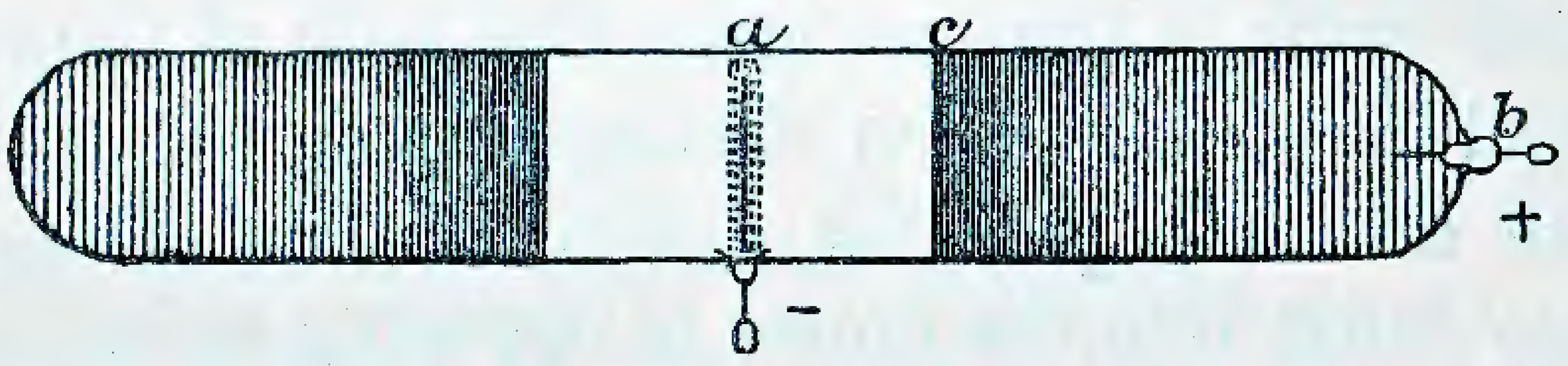
In order that no doubt may prevail as to the nature of this matter I call it "radiant electrode matter" (strahlende Elektrodenmaterie), in distinction to the so-called "glow-light," which consists of a mixture of particles of the electrodes and of gas.

If we consider the electrode particles to be infinitely small spheres, which are detached from the surface of a large sphere, we can, according to Plana's* calculation, write 1·645 for the mean density of the statical electricity of the particles of the electrode, if that of the electrode be taken as unity.

* *Mém. de l'Acad. de Turin,* 1845, 2 sér. vol. vii.

That the dark space is not identical with the mean free path of the rarefied gas is easily proved by calculation. For this purpose I carried out some experiments with air-tubes at a very small pressure. The pressure was measured by

Fig. 1.



means of a manometer which I have described in an earlier paper "Ueber die innere Reibung der Dampfe"*.

The following numbers are mean values of three series of experiments, p denoting the pressure and d the dark space ac in millimetres :—

p.	*d.*	*pd.*
1·46 mm.	2·5 mm.	3·650
0·66 ,,	4·5 ,,	2·970
0·51 ,,	5·8 ,,	2·958
0·30 ,,	7·8 ,,	2·348
0·24 ,,	9·5 ,,	2·280
0·16 ,,	14·0 ,,	2·240
0·12 ,,	15·5 ,,	1·860
0·09 ,,	19·5 ,,	1·755
0·06 ,,	22·0 ,,	1·320
0·02 ,,	?	?

At $p=0{\cdot}09$ mm. the glass tube begins to phosphoresce; at $p=0{\cdot}06$ mm. the phosphorescence is brisk; at $p=0{\cdot}02$ mm., and with an induction-current giving a 2 cm. spark, it diminishes; at $p=0{\cdot}01$ mm. it is very weak and only visible at the end of the tube. At a pressure estimated to be 0·005 mm. a faint flash through the tube is only to be seen from time to time in a perfectly dark room; if, however, at this degree of rarefaction the wire-shaped electrode be made the negative pole, phosphorescence is again apparent throughout the whole tube.

As the product pd shows, d is not inversely proportional to the pressure, which ought to be the case if it represent the mean free path.

* *Sitzungsberichte der kais. Akademie der Wissenschaften*, 1878, vol. lxxviii.; *Repertorium*, vol. xv. p. 427.

If we assume further with Stefan the mean free path of the molecules of air at 760 mm. pressure to be 0·000071 mm., there results for the mean free path at $p=0{\cdot}06$ to 0·09 mm., d about 22 mm.; and still more unfavourably at higher pressures, for example at $p=1{\cdot}46$ to 0·04 mm., d about 2·5 mm.

The dark space is thus no mean free path of the molecules of gas, and only that mean distance from the electrode to which the detached particles attain in their straight paths before they burst into the crowd of opposing molecules of gas and are diverted in all possible directions by collision with the latter. Neither is it, however, the mean free path of the particles of the electrode; for we have no right to assume that the particles of the electrode in the dark space, like the molecules of gas in the dark part of a flame, do not collide with one another.

I will here further mention that I noticed the most beautiful phosphorescence at 0·04 mm., whereas Mr. Crookes states that he has seen the same at a 50 times smaller pressure, 0·00076 mm., at which in my experiments not even strong induction-currents can pass. As far I can learn from the accounts of radiant matter hitherto published, Mr. Crookes hoped to attain the high rarefaction by removing the last traces of any gas by a suitable absorbent. Experiment has, however, taught me that it is much easier to exhaust with a well-dried pump, for the absorbing bodies contain very many occluded gases which they evolve in a vacuum. Even metals contain gases in considerable quantities*, as is easily proved by exhausting a tube with platinum electrodes so far that with a weak current a beautiful phosphorescence of the glass tube is to be seen. If afterwards a stronger current is employed, so much gas is almost instantaneously liberated from the electrode that the phosphorescence completely disappears and the tube is filled with a whitish light. If the electrode is to be sufficiently freed from occluded gases, a strong induction-current must be passed through for hours without intermission, whilst the gases which are evolved are removed by continued exhaustion.

* According to experiments by Dumas, 80 c. c. of aluminum heated in a vacuum to a temperature at which porcelain begins to melt, give off 15 c. c. of carbon dioxide and 88 c. c. of hydrogen measured at 17° and 755 mm.

Phosphorescence of Solid Bodies in Radiant Electrode Matter.

Radiant electrode matter causes in many bodies when struck by it spontaneous luminosity, a phenomenon known as *phosphorescence* and by many physicists as *fluorescence.*

The phenomenon of phosphorescence has long been known and minutely investigated by Prof. Hittorf and afterwards by Goldstein, Reitlinger, and v. Urbanitsky.

I may be allowed to cite literally here the description of this phenomenon as it appears in the second communication of Prof. Hittorf *:—

"The negative wire remains dark at the greatest rarefaction which the aspirator can produce without heating the gaseous medium ; only from the end opposite the anode does negative light issue, which, however, seems only to begin at some distance, because the mean dark layer ['dark space'] has acquired a considerable thickness. Its feebly luminous rays acquire a considerable extension, and pass through tubes a foot in length. The glass sides which bound it are fluorescent with a bright greenish-yellow light, and lose some transparence. Positive light cannot for the most part be seen. In such a cylindrical tube, therefore, the part which surrounds the positive wire and the space between the electrodes will be of a bright green, and that part at which the anode is introduced will be particularly bright, because it is opposite the end of the kathode."

"If the number of voltaic elements is increased, a green fluorescent light adds itself to that already described, as a more or less broad ring about the end of the kathode."

Whoever has once studied these matters will not doubt from the description given that Prof. Hittorf has noticed a phenomenon of so-called "radiant matter" which he designates simply "glow-light."

Mr. Crookes assumes that "radiant matter" is only present inside the dark space; but, after we have seen that the glow-light too contains particles of the electrodes, we should be justified in assuming that in the glow-light also beyond the dark space phenomena of phosphorescence would

* Poggendorff's *Ann.* vol. cxxxvi. p. 198 [*vid. supr.* p. 137].

make their appearance. In the course of my numerous experiments I have often observed that new glass tubes, even with a dark space of 10 mm., phosphoresce throughout their whole length, whilst in the interior the brush-light can be distinctly seen, especially if a circular plate of the diameter of the tube be taken as negative electrode.

I will mention incidentally that at a high degree of rarefaction the discharges of the electric current take place also *through* the glass, and that not infrequently in capillary passages filled with rarefied air, what are called striæ (*Schlieren*), very bright whitely luminous lines of light of about 1 cm. in length, are to be observed.

Very beautiful bright sparks are also seen on the parts of the electrode which are covered with glass. The discharge passes through the glass into the wire of the electrode even when the latter has uncovered parts. The spark volatilizes the metal, and hence in the case of a copper electrode is bright red.

Carbonized paper raised to a white heat for a long time by means of radiant electrode matter shows, like the diamond, a bluish-green phosphorescence on using a weak induction-current. I have examined the carbon microscopically but found no diamonds, as I had suspected on account of the green phosphorescence.

If the negative electrode is a circular disc, it becomes covered with the glow-light over its whole surface. With an increased rarefaction the discharges contract more towards the edges, but there are still to be seen in the interior of the tube blue rays of electrode matter, even with a brilliant phosphorescence of the glass sides. At a pressure 0·03 mm. and with an induction-current giving 2 cm. sparks the discharges *only* take place at the edges of the disc and along the inner glass side, and the phosphorescent action of the rays has reached its maximum, whereby in the inner part of the tube no appearance of light is to be seen.

On this subject Mr. Crookes writes* :—" But at a very high exhaustion the phenomena noticed in ordinary vacuum tubes when the induction-spark passes through them—an appearance of cloudy luminosity and of stratifications—dis-

* 'Nature,' 1879, p. 421.

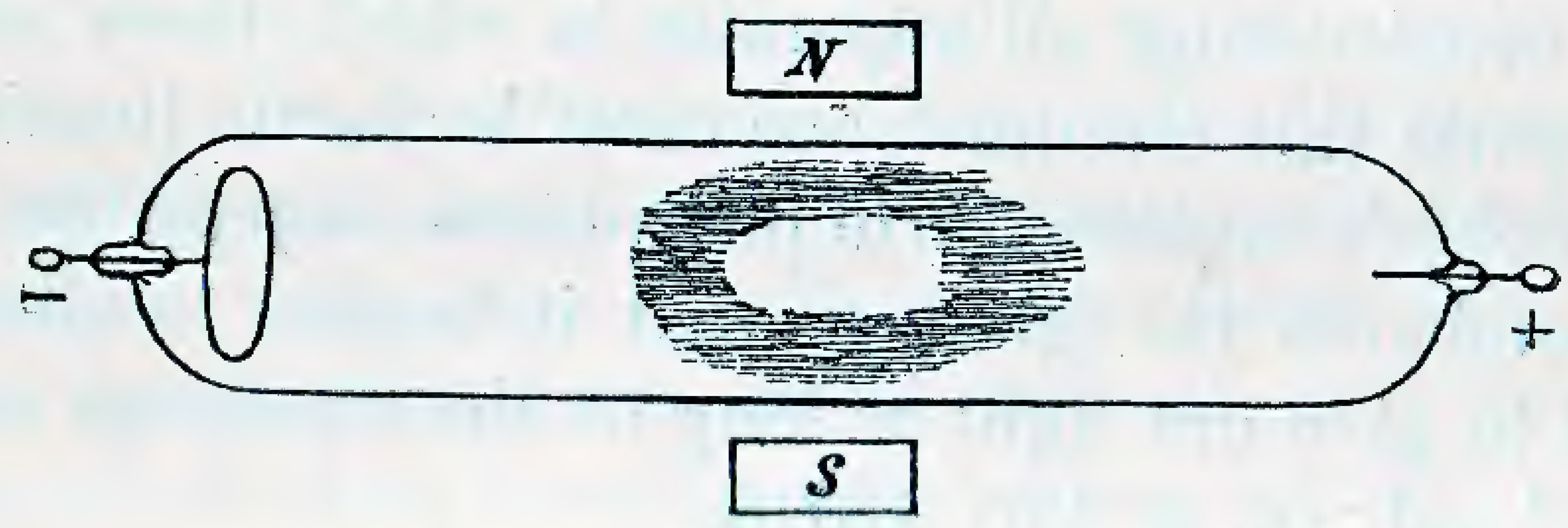
appear entirely. *No cloud or fog whatever is seen in the body of the tube,* and with such a vacuum as I am working with in these experiments the only light observed is that from the phosphorescent surface of the glass."

This circumstance may have led Mr. Crookes to the assumption that through the inner space of the tube in which no matter is apparent only "energy radiates," that here "matter and force appear to merge into one another."

The correctness of the above assertion, that the discharges *only* take place at the edges of the disc and are transmitted along the glass side is easily verified by bringing a horseshoe magnet near the side of the tube.

The light is attracted to one side and a section of the hollow cylinder of rays is seen with the glass side as an oval

Fig. 2.



phosphorescence ring. The discharge along the glass side is much more strikingly shown by the electric lamp, the description of which will follow later.

The discharge at the inner glass side causes the outer surface of the glass tube to become very strongly positively electrical, and pendulums of thin glass bulbs of the size of a hazel nut are attracted from a distance of 1 to 2 cm. and adhere to the glass side.

If the electrode be attached to an elastic wire it trembles violently under the discharges, and the flickering phosphorescent light, which is accompanied by a chirping noise, presents a magnificent display. At the same time the electricity becomes stored up in the connecting wires, and discharges itself into the external air with the well-known noise, forming ozone.

The observation may, too, be of interest which I have made with many tubes at a pressure at which the phosphorescence of the glass has already appeared, whilst the inner part of the tube is still filled with thin blue clouds of radiant electrode matter. If the glass tube be put in conducting com-

munication with the finger or a strip of tinfoil at the negative electrode on the side away from the positive pole, the blue clouds disappear and the tube shows a bright phosphorescence. Touching the piece of tube lying between the positive and negative electrodes has no action on this phenomenon.

In differently formed vessels this place of conduction may also be found between the positive and negative electrodes. If the tube at this place be strongly contracted, mere touching with the finger suffices to interrupt a current giving a 4 cm. spark. I have several times made this observation without having felt the ordinary physiological action of the induction-current. I shall refer later to this phenomenon.

The fact may also be mentioned that all bodies, for instance plates of mica, placed in the path of radiant matter become very strongly electrical, so that they adhere to wires or glass sides; hence in constructing all apparatus in which there are to be movable parts this circumstance must be borne in mind.

Mr. Crookes's explanation of phosphorescence is that radiant matter bombards the glass so that it begins to vibrate, and continues to give out light as long as the discharge continues (' Nature,' vol. xx. p. 420, 1879).

On the other hand Prof. Hittorf writes as follows about it:—"As I showed in my first communication, there are formed at the small cross section (of a wire surrounded with a tube up to the last section), if it is negative, very hot, slightly luminous *radiant particles of gas emitting light of a high refrangibility*, which extend straight through the whole tube to the opposite side and cause this to phosphoresce. . . . If now the calcium sulphide be allowed to come into contact with the negative glow-light emanating from the cross section, the spots touched show an intense white luminosity which causes strong after-images in the eye when held near"*.

Radiant matter (glow-light) would therefore, also, according to the views of Prof. Hittorf, consist of particles of gas, and the latter, too, would have the property of emitting light of high refrangibility and cause phosphorescence.

Dr. Goldstein † is also of the same opinion as to the cause of phosphorescent light.

In order to test the correctness of this hypothesis a circular

* Wiedemann's *Ann.* vii. p. 586 [*vid. supr.* p. 207].

† *Wiener Berichte*, 1878.

aluminum plate in which a section in the shape of a cross was covered by means of a plate of quartz 4 mm. in thickness was placed in the path of the rays. If the assumption mentioned were correct a phosphorescent cross on a dark ground must be formed on the glass side; for rays of higher refrangibility must pass through the quartz plate and cause phosphorescence on the side. This result, however, as was to be expected, was a negative one.

In the following pages two pieces of apparatus are described which show some interesting phenomena of phosphorescence.

The plate of mica in the centre of the globe (fig. 3, p. 252) is about 4 cm. long and 3 cm. broad, and is coated with chalk on the side turned away from the saucer-shaped electrode. By using the plane electrode first as negative pole, the covering of chalk on the mica plate is directly struck by the rays and shines with a very bright orange-coloured phosphorescence. On breaking the current the feeble luminosity of the chalk still lasts for some time. If, however, the saucer-shaped electrode is afterwards made the negative pole, the coating of chalk shows first of all a very bright phosphorescent spot, forming after some seconds a ring of light which becomes continually larger. If after once breaking the current the *same* kathode is again used, no phosphorescent spot is formed; the phenomenon reappears, however, if after a few minutes the coating of chalk is first of all directly irradiated.

The explanation of this phenomenon presents no difficulty. The rays from the kathode which strike the bright side of the lamina only cause *indirectly* the phosphorescence of the layer of chalk by heating the lamina. The phosphorescence is excited afresh by heat, and as the latter spreads out in all directions in the plate of mica from the focus, continually larger circles will begin to be luminous. But this glowing, in consequence of the heating, only continues for a limited time, and the extinction begins therefore in the focus of the kathode-rays. The phosphorescent spot breaks up and forms a luminous ring which increases at its outer and decreases at its inner periphery, and in this way becomes larger and larger.

At a high degree of rarefaction and with a more powerful

induction-current the plate of mica, when the phosphorescent ring is entirely extinguished, shows a small round and whitish spot, which is caused by a partial glowing of the mica lamina.

The experiment succeeds best of all when the mica lamina is *directly* irradiated by a single flash only, and after about 50 to 60 seconds is warmed from the back. The experiment may also be reversed. The mica lamina is warmed from the back first of all for about 3 to 4 seconds, and afterwards the layer of chalk is irradiated with a single flash. A dark circular disc is then seen on a bright phosphorescent ground, which is explained by the fact that the heated spot very quickly loses its phosphorescence.

This apparatus shows thus in an elegant form, not only the property of self-luminous bodies of being *caused to phosphoresce*

Fig. 3.

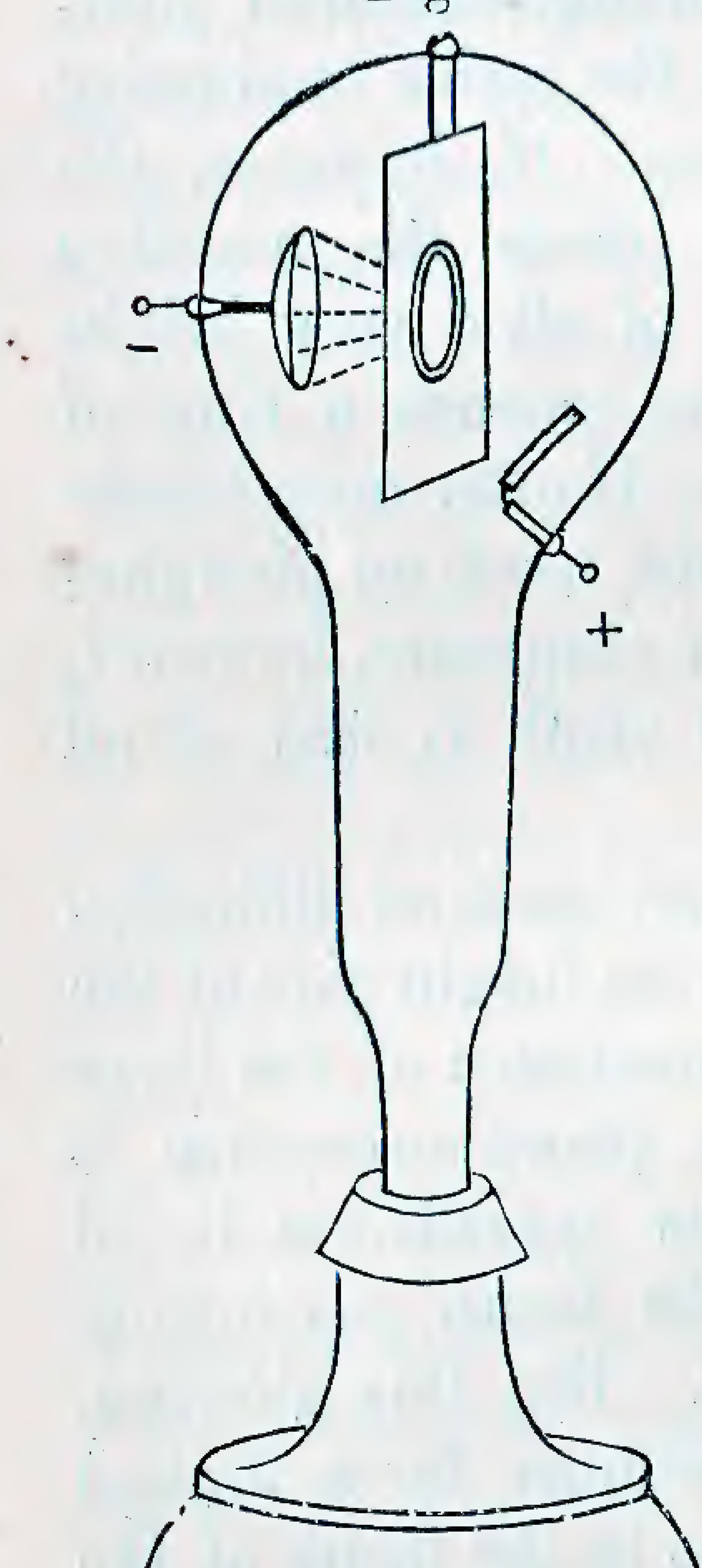
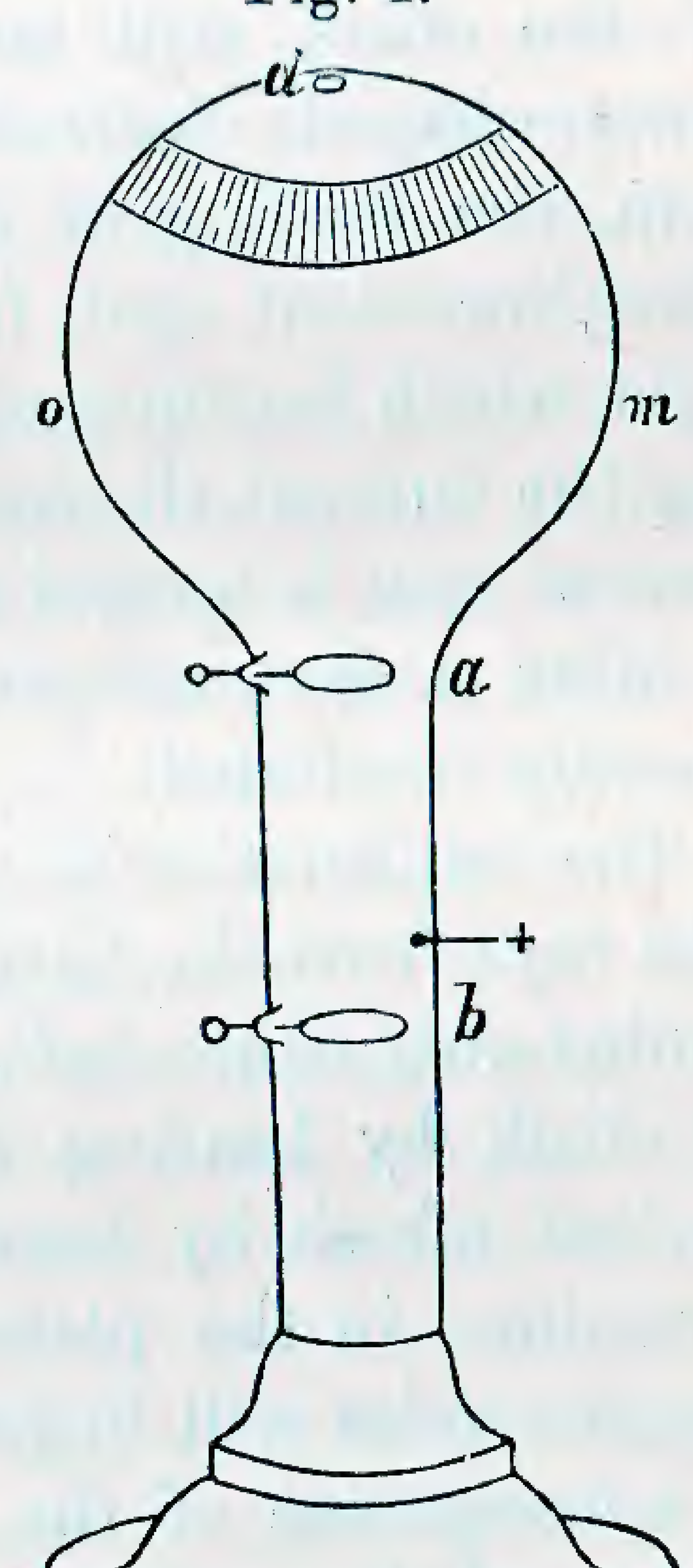


Fig. 4.



again by heating if they have first of all been made self-luminous by direct radiation but remain dark on further heating, but also allows the velocity with which heat is transmitted in any plate to be demonstrated.

If any body be placed on the path of the kathode-rays a shadow is formed on the opposite glass side, which appears evident if the rays consist of moving particles of bodies which proceed in straight lines. As, moreover, many of these particles will collide with each other, some of them must be diverted sideways from the direct course of the rays and produce phosphorescence, though feeble in the shadow of the body. The phosphorescence in the electrical shadow can also be very bright if a body be placed in it which is sensitive to phosphorescence, such as diamond or any sulphur compound. The apparatus in fig. 4 serves to demonstrate this phosphorescence in the electrical shadow.

At *d* a splinter of diamond is stuck on by means of gum, and the mica plate *a* serves as the body producing the shadow. The rays which pass between the plate of mica and the glass side produce on the globe a bright phosphorescent ring, in the centre of which, in the shadow of the mica plate, the diamond splinter too shines manifestly in consequence of the particles of the electrodes turned on one side from the kathode-rays.

In conclusion I will try to give an explanation of the phenomena of phosphorescence.

In the sense of the æther theory of electricity, to be afterwards discussed, on which Franklin, Secchi, Edlund, and others have tried to explain several electrical phenomena, the negatively electrical particles of the electrode have a deficiency of æther. Certain parts of the glass tube will be generally positively, others negatively electrical, or, perhaps too, behave indifferently; that is, they have either an excess or a deficiency of æther, or else a normal quantity. A twofold effect will result from the collisions of the negatively electrical particles of the electrode with the glass sides. *Firstly*, in consequence of the impacts of the particles flying with great velocity, the particles of glass are set in a vibratory motion which will manifest itself as *heat*. *Secondly*, the relative excess of æther (difference of potential) will be equalized between the part struck and the colliding particle of the electrode, causing a concussion in the envelopes of æther of the molecules. If the spot struck and the colliding particle of the electrode have equal quantities of æther, no equalization and only a concus-

sion of the envelopes of æther takes place, which is the more energetic the stronger are the discharges of the electrical current. Just as a calm surface of water struck by drops of rain becomes covered with little ripples, so each point of the glass side struck becomes the centre of waves of æther which we see as phosphorescence. As further, differently stretched strings of an æolean harp are set in vibration by a current of air, and each of them gives a note corresponding to its tension, so also each phosphorescent body shines with the light peculiar to it, dependent on its inner structure and the state of density of the æther. At low degrees of rarefaction, however, the particles of the electrode during their motion meet with many molecules of gas, and after they have partially interchanged quantities of æther meet the glass sides, the latter will either not phosphoresce at all or only slightly, whereas the envelopes of æther of the molecules of gas struck are caused to vibrate, and the gas shows the phosphorescence peculiar to it. The luminous phenomena of gases in Geissler's tubes were for long erroneously considered, according to Plücker and Hittorf, as a luminosity of glowing gases. The more exact investigations of Prof. Hittorf* have, however, shown that we have here merely to do with phenomena of phosphorescence. Experiments of Prof. E. Wiedemann in this direction showed that the temperature of the luminous gas in the tube used by him must be under 60° C.

If the tube be subjected to a strong phosphorescence for at least a minute, it shows in a perfectly dark room after breaking the current a white after-luminosity for about 5 to 6 minutes.

It may be here, too, remarked that the envelopes of æther also are set in vibration when the particles of the electrode are detached, and these latter therefore must become luminous before they collide with particles of gas or side of the tube. It can be explained in this way that the "dark space" is not absolutely but only relatively dark, since the particles of the electrode themselves produce a blue phosphorescence.

* Wiedemann's *Ann.* vii. p. 580 [*vid. supr.* p. 250].

Rectilinear Propagation of Radiant Electrode Matter and Shadows of Irradiated Bodies.

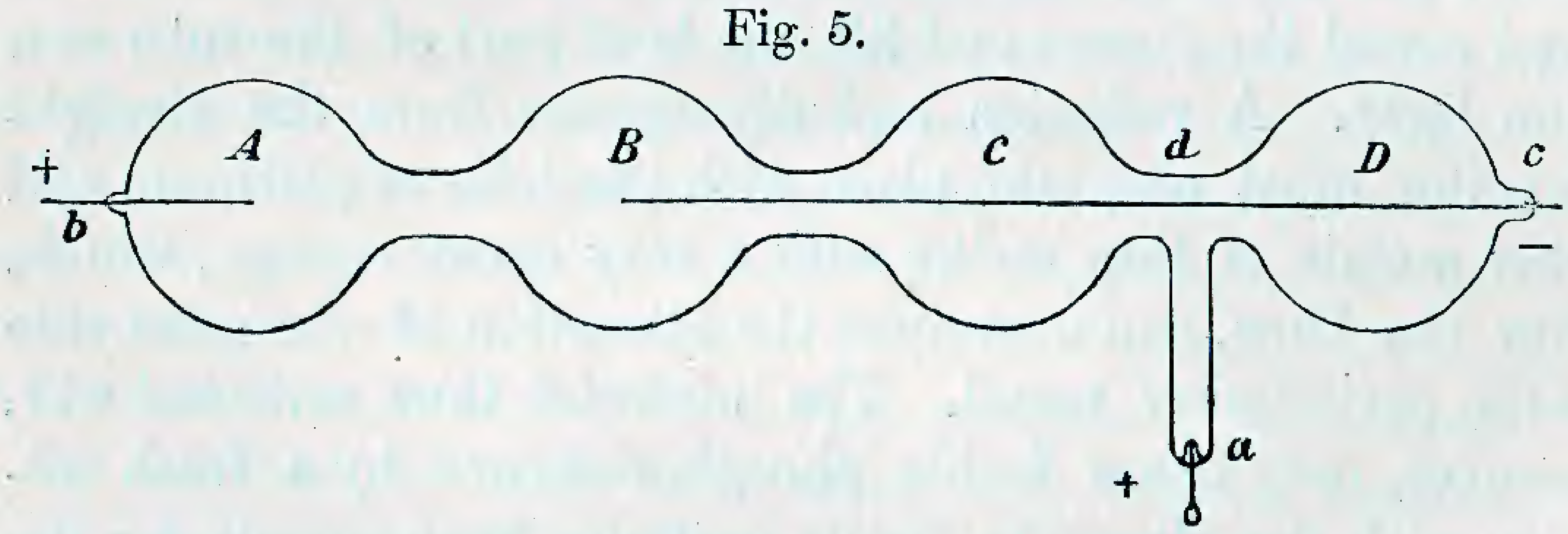
The property noticed by Mr. Crookes that radiant electrode matter moves in a straight direction and throws a shadow of a body irradiated by it on to the opposite glass side, had also been observed by Prof. Hittorf. He proved the rectilinear motion by means of a tube bent at a right angle *, and writes as follows about the shadow :—" Any solid or liquid, whether insulator or conductor, which is in front of the kathode shuts off the glow-light which lies between it and the kathode; there is no deflection from a straight line." If in such circumstances " any object is interposed in the space filled with glow-light, it throws a sharp shadow on the fluorescent side, since its surface just cuts off the luminous cone proceeding from the kathode as apex."

In the same place is further observed, " If the glow-light spreads out in right lines from the points of the kathode, it must be independent of the direction of the positive rays."

At high degrees of rarefaction, however, the irradiation of electrode matter is, as I have often noticed, stronger on the side of the negative electrode plate facing the anode than on the opposite side. Moreover, the radiation seeks the spot on the kathode which lies nearest to the anode.

In a bulb-tube, of the shape represented in fig. 5, in

Fig. 5.



which one electrode c was about 15 cm. long, phosphorescence of the glass tube was seen at a certain rarefaction along the whole length of the electrode c, and independently of the position of the positive electrodes a and b. At a greater rarefaction the phosphorescence receded into the bulbs B

* Poggendorff's *Ann.* cxxxvi. p. 8 [*vid. supr.* p. 116].

and C and finally into B alone, if the positive pole were at *b*. If *a* were made the positive pole, the phosphorescence in B disappeared, and the part *d* of the connecting tube nearest to the anode *a* showed a very bright phosphorescent spot.

In this tube I also noticed very sharp alternately dark and light phosphorescent lines wound obliquely like a screw round the electrode as axis covering the glass side as far as the electrode extended.

By using as negative electrode a wire about 4 cm. long, twisted 20 times about its axis, I obtained at the surface of the bulb A, as far as the electrode extended, a number of light and dark circular lines parallel to one another, their plane being perpendicular to the electrode. I thought therefore that these lines were formed in consequence of microscopically small inequalities in the surface of the wire.

The impression of a coin on the platinum foil when used as an electrode only gave a very indistinct and blurred image.

If the radiant electrode matter which causes the phosphorescence consist of material particles, it is not apparent why, in general, no reflexion takes place at the side and why, too, it should not turn round a corner. It is a matter of course that no reflexion takes place in those cases in which the particles of the electrode attach themselves to the glass sides; but as aluminum forms no, or, at any rate, only a very slight deposit, which very probably arises from particles of other metals contained in the aluminum, the electrode matter will bend round the corner and fill the bent part of the tube as a blue light. A reflexion and divergence from the straight direction must also take place with particles of platinum and other metals if they strike with a very great energy, which, after the blow, can overcome the attraction of the glass side on the particles of metal. The material thus reflected will, however, only cause feeble phosphorescence by a fresh collision with the glass side, for its particles have already for the most part neutralized their electrical charges, and have also lost something of the energy of their molecular motion.

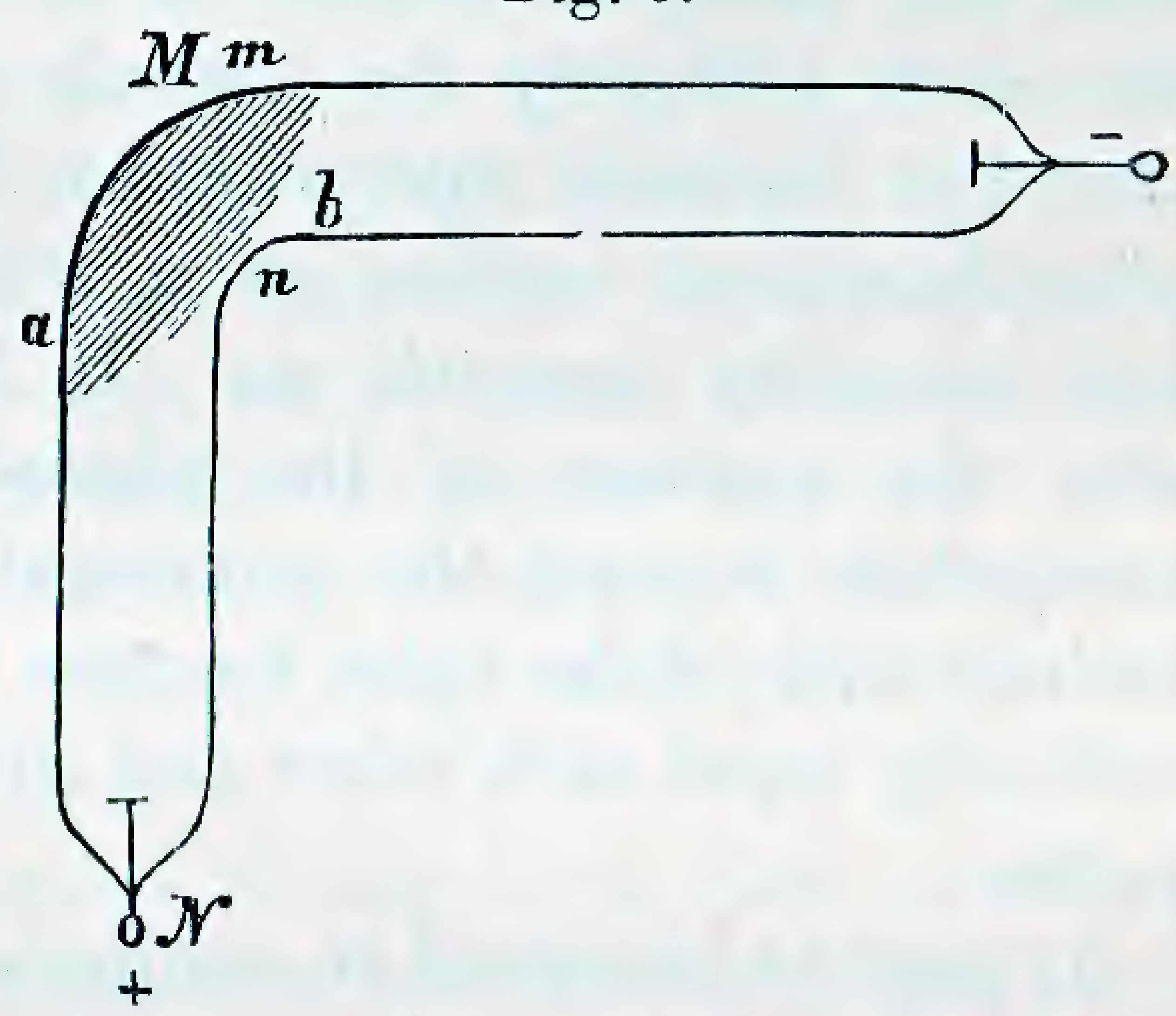
The particles of the electrode will move after their reflexion in one, or in all possible directions, according as their velocity is great or small respectively, which latter will be the case for the most part after reflexion.

I will explain here a phenomenon of phosphorescence

which Dr. Goldstein* has misunderstood, and which has led to the assertion that the anode light, at any rate at very small densities, has the same properties as the kathode light, namely a rectilinear propagation and phosphorescent action.

We see from the following how Dr. Goldstein arrived at this :—

Fig. 6.



If the positive light fills a strongly evacuated bent cylindrical tube, a bright phosphorescent surface is seen at the outer side of the bend, a semi-oval of parabolic shape. The sharply marked vertex *a* is turned towards the positive end of the tube. On the opposite side *b* turned towards the kathode, the definition fades away. The surface with its sharply marked end extends a little towards the positive side, beyond the extension of the sides of the negative limb.

If several such bends be made in the discharge-tube, a similar phosphorescent surface appears at the outer side of *each* bend. It follows from this on Goldstein's view that it is not the kathode rays, but the *positive light* itself which causes the phosphorescence, for the kathode rays can "at most cause a luminosity at the first bend, but not extend beyond the first bend on account of their rectilinear propagation."

Wires suitably fixed give sharp shadows on the phosphorescent sides, and their position shows that the phosphorescence is excited by rays which "extend very near and parallel to the side of the tube *from the side of the kathode towards the positive side.*"

By experiments made with tubes with several bendings, Goldstein arrived at the following result :—"The *positive* light of a highly rarefied gas consists of rectilinear rays which are transmitted from the positive to the negative side. The rays form a slightly conical brush, whose axis is the axis of the cylindrical tube ; where this brush cuts the side of the vessel, the parts of the rays immediately adjacent to the side cause phosphorescence in it."

* *Neue Form elektrischer Abstossung von Dr. Goldstein.*

The phenomenon of phosphorescence described by Dr. Goldstein is not caused by the "positive light" but by the particles discharged from the *negative* electrode which strike the glass side *am* (fig. 6) at different angles of incidence, after their rectilinear motion through the negative (horizontal) limb. If we consider, moreover, the circumstance that the phosphorescence of the glass side must be fainter the more obliquely the kathode rays strike it, it is evident that the kathode rays cause a bright and sharply defined phosphorescent surface at *a*, which gradually loses its limit and intensity towards *m*. It is no less easily explained, why the outlines of the phosphorescent surface must be somewhat beyond the prolongation of the negative (horizontal) limb of the tube, because the particles of the electrode mutually repel each other and diverge from their rectilinear paths.

It may be observed in connexion with this, that Mr. Goldstein's remark is not correct when he states that "the kathode rays cause at most a luminosity at the first bend, but cannot extend beyond this," because the particles of the electrode experience reflexion at each bent point (*a m*) of the tube, and must therefore also give rise to a similar phosphorescent surface at the outer side of *each* individual bend.

If the tube near the negative electrode has become coated with a strong metallic mirror, this acts at a greater rarefaction as an electrode. The discharges of the current proceed from the electrode to the surface of the mirror, and from this into the interior of the tube. As, however, the particles of the electrode only hang loosely on the glass side, they become raised to redness and volatilized by the metallic particles striking against them, partly by this motion of heat, partly mechanically by discharges which take place from the glass side into the interior of the tube. If the current be strong (8 cm. spark), red fiery rays are seen to shoot out with a crackling noise from the sides of the mirror perpendicular to the surface towards the middle of the tube, and the tube is flooded from time to time with a blue glow-light, accompanied by a simultaneous disappearance of the phosphorescence of the glass. Platinum electrodes are most suitable for this, since they give a very strong mirror.

As already observed, bodies which are illuminated by electrode matter throw a shadow on the phosphorescent glass side. If the body be turned round about, a much more vivid phosphorescence appears in place of the shadow, and a bright image is seen upon a less bright ground. Mr. Crookes gives an explanation, which is physiological rather than physical, by saying that the glass becomes insensitive by the bombardment of molecules of radiant matter, and "tired by the enforced phosphorescence" *. I think, however, that the cause is to be sought in the fact that, after repeated experiments, the glass side becomes really coated with metallic particles, and hence the phosphorescence is feebler. The phosphorescence must also decrease in consequence of strong heating of the glass side; a faint heating would only make the phosphorescence still brighter.

In the apparatus represented in fig. 7 a mica screen in which a star is cut out is suspended at one side of the plate-shaped electrode of aluminum. The star is suspended at some distance on the opposite side of the electrode, and on irradiation by means of electrode matter a bright star is seen on a dark ground, and on the opposite wall a dark star on a bright ground.

Fig. 7.

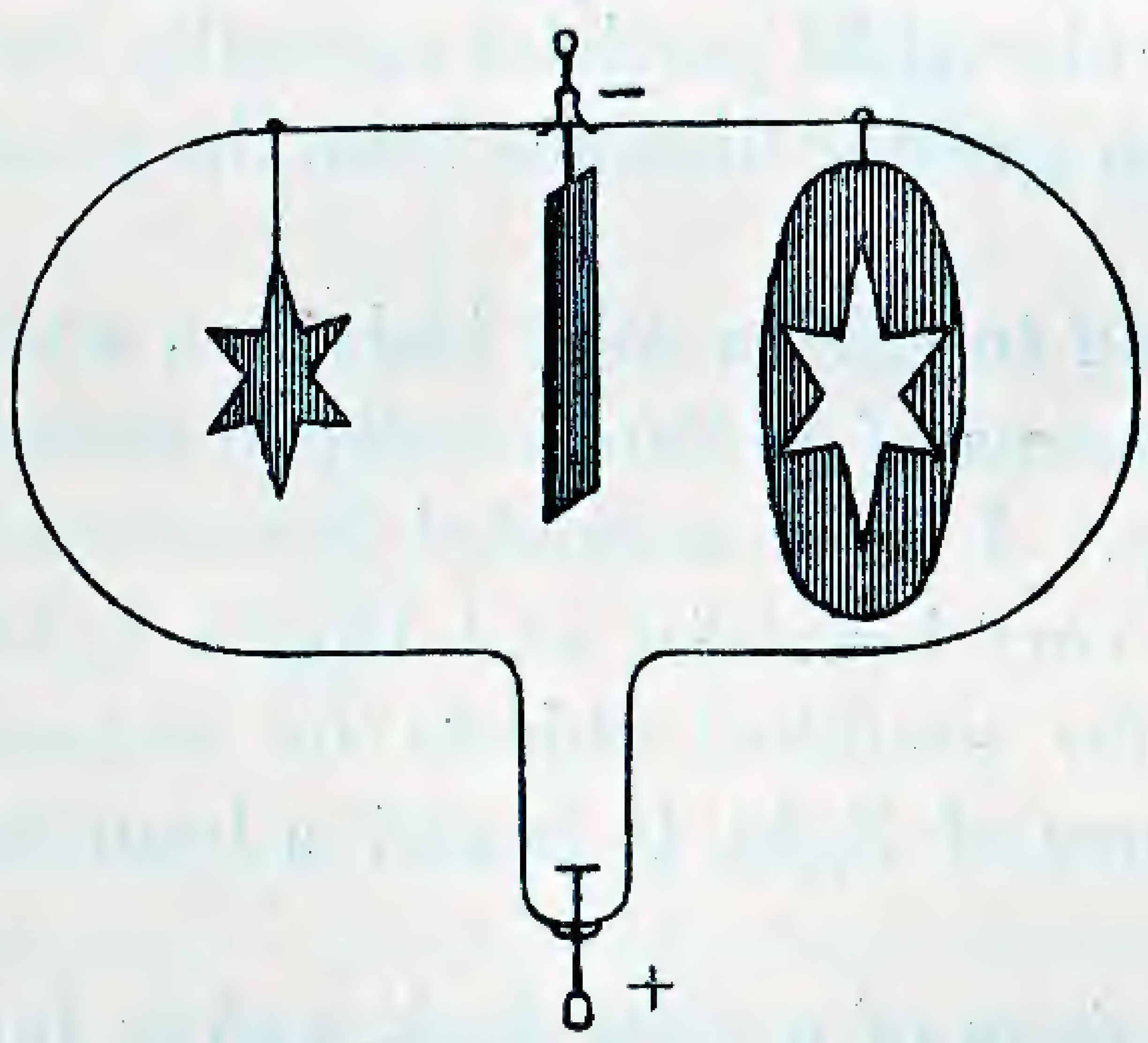


Fig. 8.

If the experiment be so arranged that, whilst the current is closed, a magnet simultaneously deflects the rays, they will also fall obliquely about the edges and meet dark spaces of the glass side. The sharp contours of a brighter and less bright star are *simultaneously* seen which partially cover each

[* 'Natüre,' vol. xx. p. 419, 1879.]

other (fig. 8). The inversion of the shadows thus depends not upon the "insensitiveness" for impacts, but upon the fact that the glass side in the shadow is still kept clean, whereas at the exposed parts it is covered with metallic particles.

Thermal and Luminous Action of Radiant Electrode Matter.

If a plate-shaped electrode be curved, the particles which proceed from it perpendicular to the surface will meet in a focal line or focus according to its curvature. The points of union lie beyond the centre of curvature of the surface. I thus determined experimentally the position of the point of union of a hemispherical cup of diameter r to be at a distance $1{\cdot}7\,r$ from it. In these points of union of the rays the particles of the electrode collide with great violence, and a large part of the energy of their progressive motion is changed into atomic motion. So much heat is there generated, that even difficultly fusible metals are melted. In this way Mr. Crookes has melted platinum, iridium, and glass. But Prof. Hittorf, too, has described these fusion experiments in his second communication *. He experimented with wire-shaped electrodes. At a distance of 1 to 2 mm. from the negative electrode the positive platinum wire became incandescent and fused to a globule. It is self-evident that this fusion could not take place at a greater distance, for the electrical particles mutually repel one another, and disperse at a greater distance from the point-like end of the electrode.

It naturally suggested itself to raise a solid body to a white heat and *incandescence* by means of radiant electrode matter, and to utilize this for a lamp. I have succeeded in constructing such a lamp, giving a very beautiful and bright light; and although little suited for practical objects on account of the smallness of the source of light, it is still a beautiful experiment †.

The lamp (fig. 9) has the form of a glass flask, and is furnished with a spherical aluminum cup of 21 mm. radius, which serves as negative electrode. At a distance of 36 mm.

* Poggendorff's *Annalen*, cxxxvi. pp. 210, 211 [*vid. supr.* p. 147].

† Since Spottiswoode constructed an inductorium giving sparks a metre in length, it has been possible to raise larger pieces of carbon to incandescence, and to use the lamps for purposes of illumination.

from it is a small cone of carbonized paper, which is fastened by means of a thick platinum wire and a glass rod to the plate-shaped positive electrode.

Paper which has been very carefully carbonized, and even raised to a white heat, still contains, after cooling, very much occluded gas, and in order to remove this and to raise the carbon to a red and afterwards to a white heat the flask must be exhausted for many hours, applying at the same time a strong induction-current of about 10 to 12 cm. spark. During this process it is interesting to observe the spectrum, which shows rays of a greater refrangibility the more strongly the carbon glows. At a white heat the carbon shows a perfectly continuous spectrum. If it is thin and the lamp be surrounded

Fig. 9.

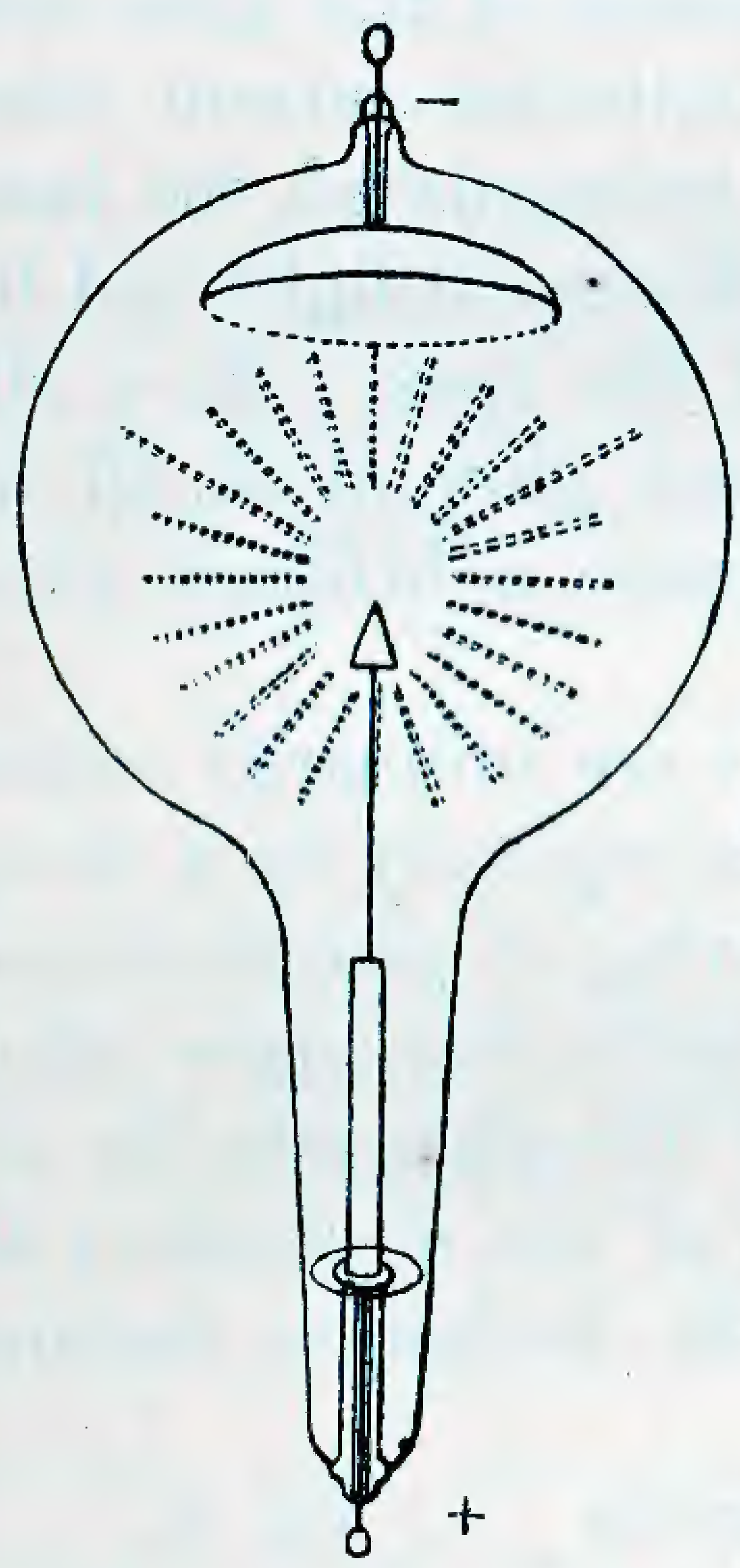
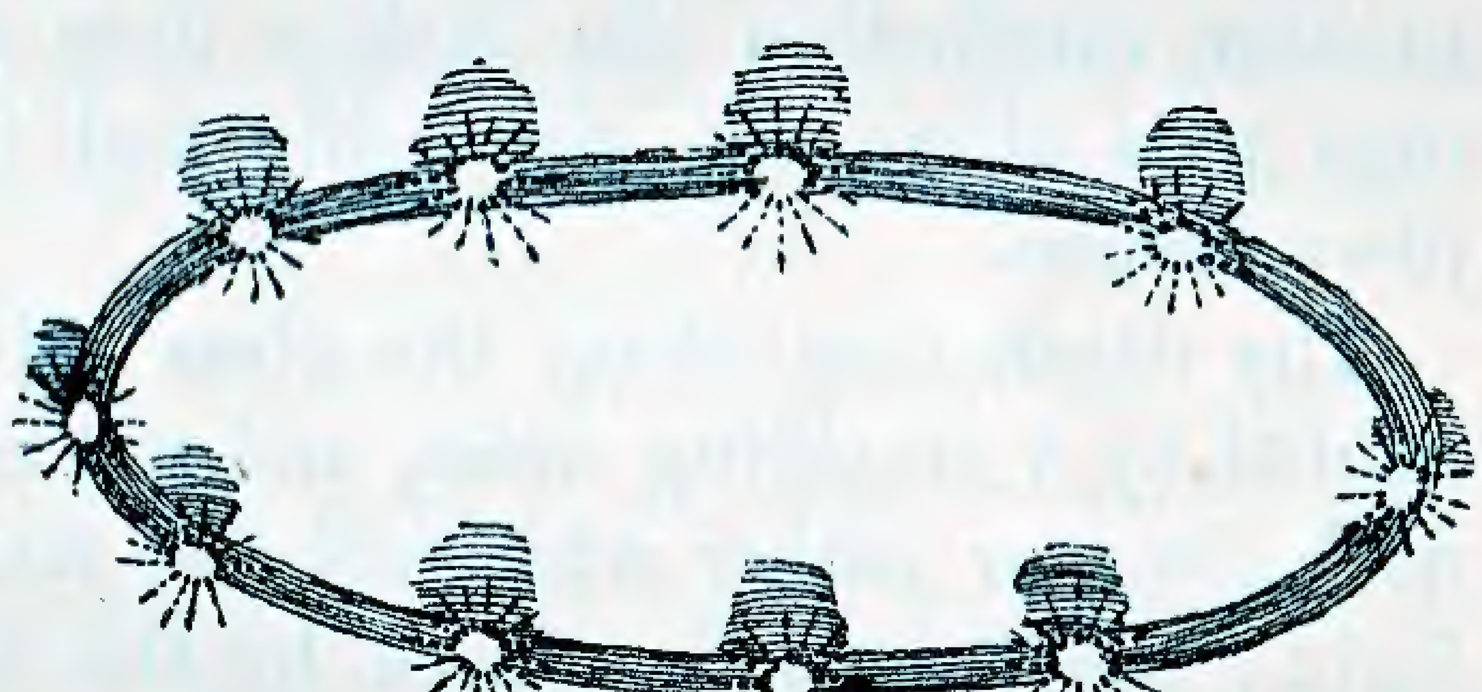


Fig. 10.



with an opal globe, a faint flickering of the diffused light is observed. If the point-like source of light be examined in a mirror which is oscillated about one of its edges with the hand, an elliptical red band is seen (fig. 10), showing at different points very bright images of the white-hot flashing carbon, covered at one side with a blue glow-light.

The white heat of a thin carbonized paper is therefore not continuous but intermittent; it is raised to a white and diminished to a red heat at each discharge of the induced

current. Even after long use the carbon does not show the least disintegration or waste.

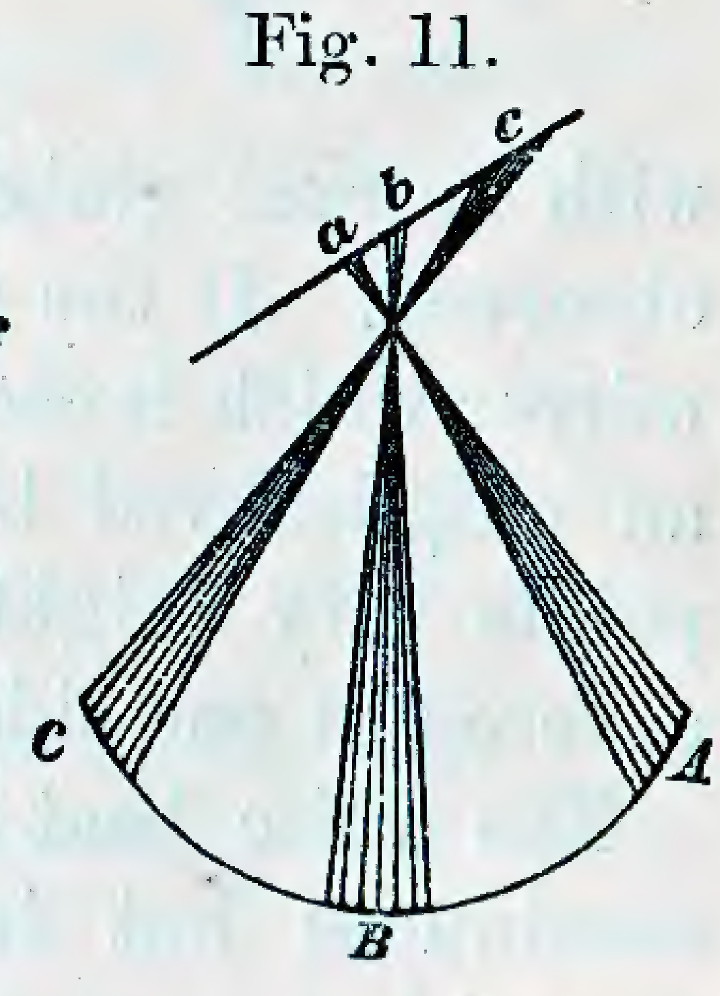
If a carbon so prepared be irradiated by the discharges of a weak induced current (2 cm. spark), it shows on its surface the bluish-green phosphorescence of the diamond already mentioned.

A larger piece of carbon is only brought to a glow at that point which is in the focus of the rays. If the focus be displaced to another spot in the carbon by means of a magnet, so much gas is at once set free that the lamp is extinguished and the carbon is raised to a red heat only.

For this experiment the rarefaction only needs to be about 0·04 mm., at which pressure the most beautiful white glow is maintained. At a further rarefaction, the intensity of the light diminishes, and the phosphorescence of the glass side increases. If the discharge of the induction-current takes place along the glass side, the light is extinguished, the lamp shines in a very beautiful green phosphorescent light, and the cone of carbon only glows faintly at the apex. At a still greater rarefaction the carbon does not glow at all, all the rays pass along the glass side and cause a brilliant phosphorescence.

The discharges along the glass side are ordinarily accompanied by a crackling noise, and not infrequently by a strong flickering, or rather whirlpool-like waving of phosphorescent light; the former is caused by the feeble discharges which take place from the wires and sides of the glass into the air, and also from the trembling motions of the electrodes; the reason for the latter may be that the discharges fluctuate about certain places on the kathode.

Fig. 11.



In order to cause larger pieces of carbon to glow, a leaf of carbonized paper was fixed at 45° to the vertical in the focal line of a cylindrical electrode of aluminum of 20 mm. radius.

A cylindrical electrode was formed with a piece of aluminum foil 3·2 cm. × 2·5 cm. As the carbon was not fixed exactly in the focal line, three focal lines were formed, which are to be explained by the fact that

the discharges of the current (10 cm. spark) were not distributed equally over the whole surface of the electrode, but took place at the three positions A, B, C (fig. 11), which was also evident from the phosphorescence on the glass sides.

If the current were interrupted, the red glowing focal lines disappeared immediately. This, as well as the diminution to a red heat of the white-hot carbon referred to, proves that at this high degree of rarefaction, at which the thermal conductivity of the gases can only be small, *the radiation of heat must be very considerable, that thus the constant of thermal conductivity given by the experiments must not only be considered as the measure of the thermal conductivity of the gas but also due to a no small radiation of heat in a vacuum.*

Electrostatic and Electrodynamic Action of Radiant Electrode Matter.

The interaction between the glow-light and a magnet has already been investigated by Plücker, and in a very exhaustive and exact manner by Prof. Hittorf; Mr. Crookes's work, therefore, in this direction can offer us nothing new, with the exception of the conclusions he has deduced from his experiments, to which, however, I cannot assent.

Mr. Crookes admits that, in less strongly rarefied spaces, the discharge passes from one pole to another "carrying an electric current as if it were a flexible wire," but disbelieves that the current of radiant electrode matter from the negative pole carries with it an electric current.

Mr. Crookes believes he has found a proof of this by producing two currents of radiant electrode matter close to one another on a phosphorescent screen, and shows that they mutually repel each other. He then says—"If the streams of radiant matter carry an electric current, they will act like two parallel conducting wires, and attract one another; but if they are simply built up of negatively electrified molecules they will repel each other" *.

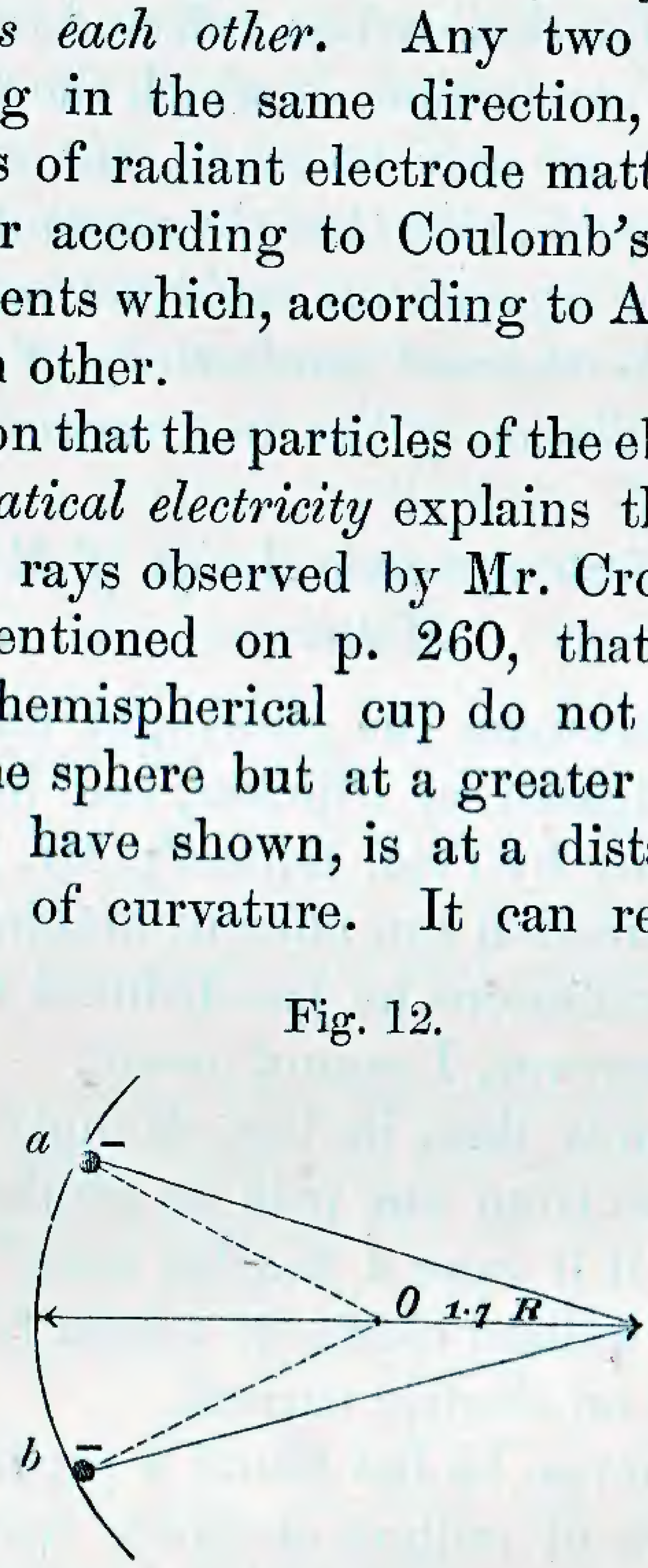
The truth lies between the two. The radiant electrode matter consists of particles charged with negative electricity, which, moving with a very great velocity in a straight direction,

* 'Nature,' 1879, p. 438.

convey the electricity *convectively*, and effect the conduction of the current between the two poles. If two such particles, charged with statical electricity, were at rest, they must repel each other according to Coulomb's law; and if they were endued by any cause with motion in the same direction, it is not apparent why, during this motion, they should behave differently *towards each other*. Any two negative electrical particles moving in the same direction, thus also any two parallel currents of radiant electrode matter, would therefore repel each other according to Coulomb's law in distinction to galvanic currents which, according to Ampère's law, mutually attract each other.

The assumption that the particles of the electrode are charged with *negative statical electricity* explains the repulsion of two parallel kathode rays observed by Mr. Crookes as well as the phenomenon mentioned on p. 260, that the kathode rays emitted from a hemispherical cup do not come to a focus at the centre of the sphere but at a greater distance, which, as my experiments have shown, is at a distance of 1·7 times r from the centre of curvature. It can readily be seen that

Fig. 12.

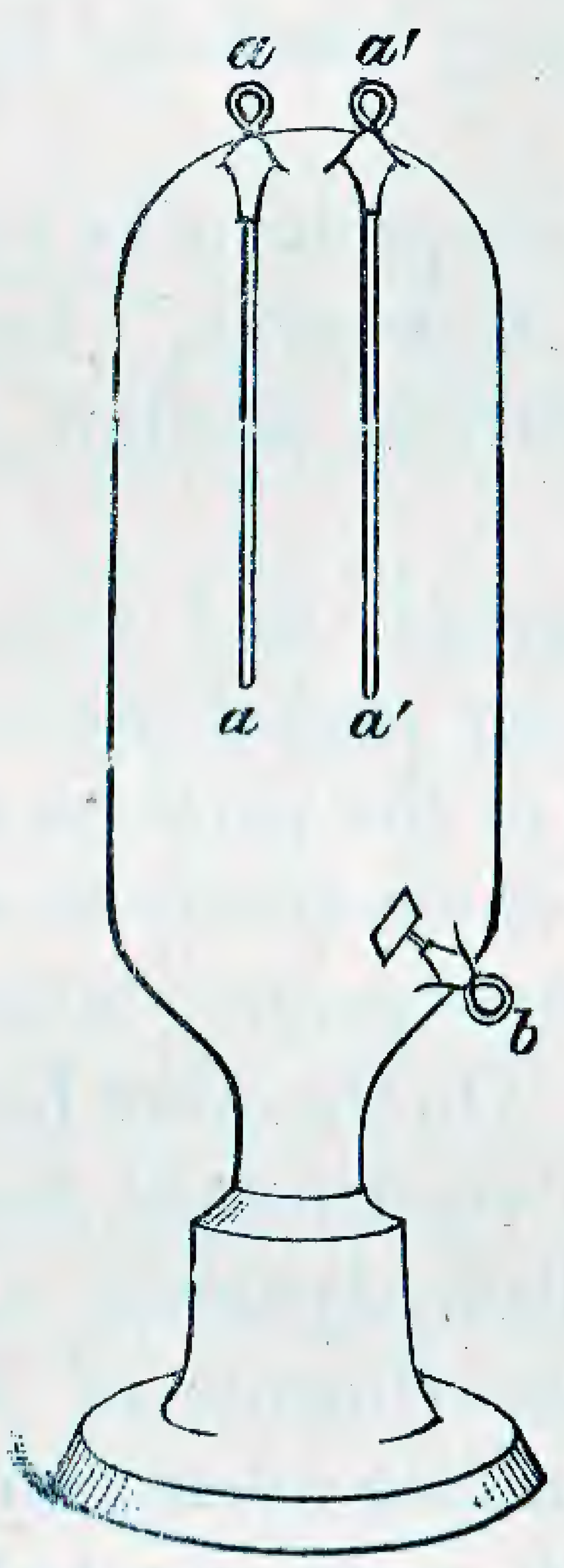


the particles of the electrode issuing from the points a and b, by mutually repelling each other, cannot meet at the centre O but at somewhere about O', and that the distance OO' will be greater the greater the repulsion between the particles of the electrode.

It is just as easily explicable that the phenomenon of a body irradiated from the kathode gives a *wider* shadow upon the opposite side when itself negative than when it is not electrified, as Dr. Goldstein has observed in an apparatus represented in fig. 13. If in the latter the aluminum wire $a\ a$

forms the negative electrode, an equally stout aluminum wire $a'\ a'$ gives a narrow shadow on the opposite side, which

Fig. 13.



at once becomes wider if the eyelet a be connected to a' by a wire. In the first case the particles discharged from the

Fig. 14.

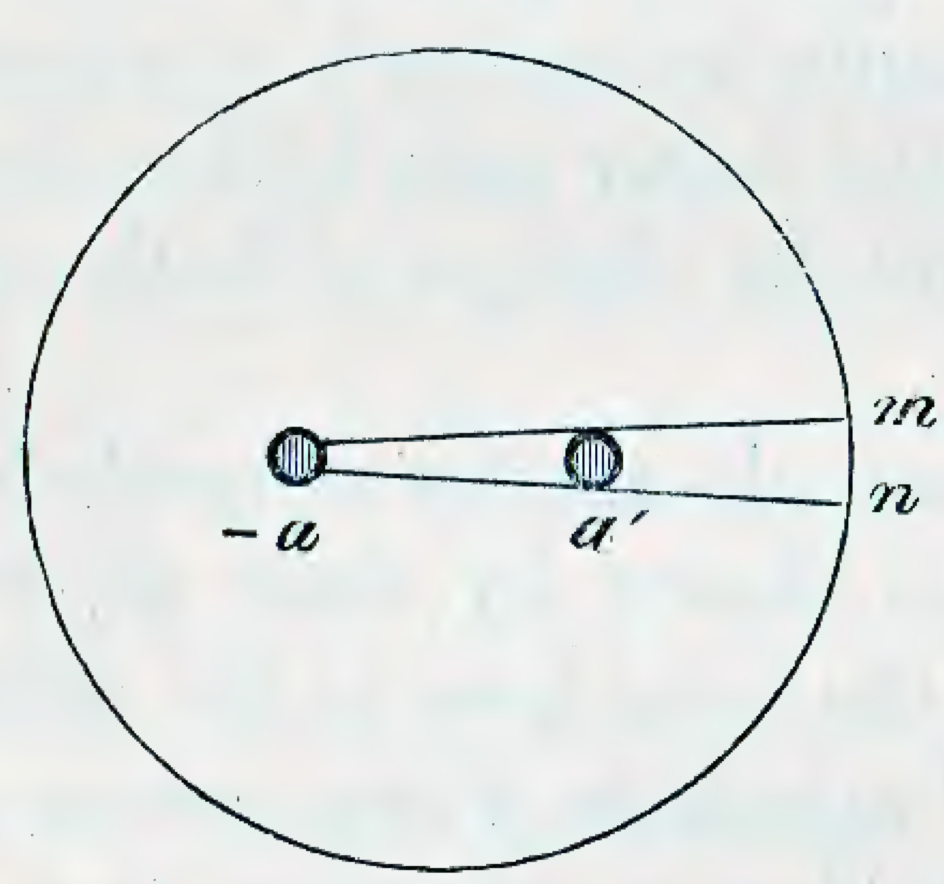
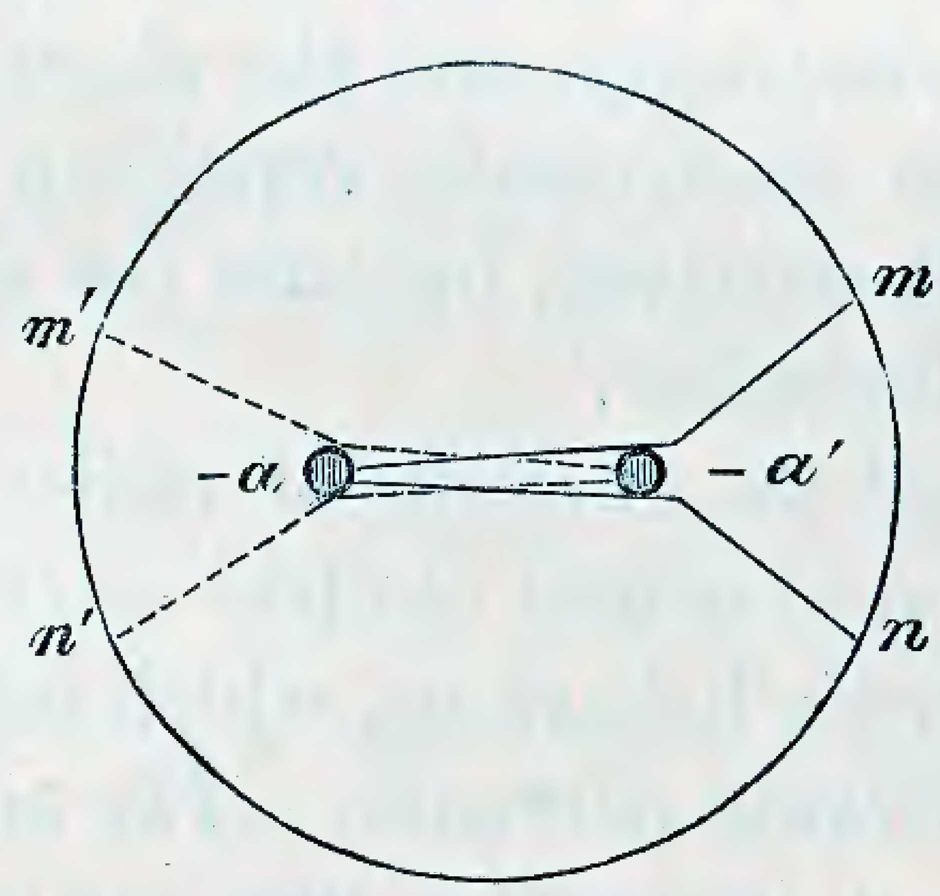


Fig. 15.



kathode a pass the wire $a'\ a'$ without being diverted from their rectilinear path, and the shadow mn, fig. 14, is formed on the opposite side. If, on the other hand, $a'a'$ itself be negatively electrical, fig. 15, the approaching particles will be diverted and move in bent directions $a\,a'\,m$ or $a\,a'\,n$. The wire $a'\ a'$ irradiated by $a\ a$ gives a shadow $m\ n$ on the opposite side (fig. 15) ; and since, moreover, $a\ a$ is also irradiated by $a'\ a'$,

the wire $a\,a$, too, gives a wide shadow $m'\,n'$. The parts of the sides $m\,n$ and $m'\,n'$ are, however, irradiated respectively, too, by $a'\,a'$ and $a\,a$, owing to which the shadows are only relatively and not absolutely dark. The parts of the sides $m\,m'$ and $n\,n'$ are simultaneously irradiated by both electrodes $a\,a$ and $a'\,a'$.

Dr. Goldstein, in his comprehensive paper, entitled "*Eine neue Form elektrischer Abstossung*," has described this experiment with the electrical shadow without having explained it.

It may here be remarked, that two currents of radiant electrode matter would very probably also attract one another if the velocity of motion of the particles of the electrode were of the same order as that of electricity in solid conductors. At a lower velocity the electrodynamic action is overpowered by the electrostatic action. On the other hand, by the interaction of galvanic currents, the electrostatic repulsion disappears in comparison with the electrodynamic attraction, but is not equal to zero, as the experiments of Herwig show*. He found that the electrodynamic attraction of two coils was different according as both were inserted in the same circuit close to the same, or to different poles. The electrodynamic attraction is somewhat smaller in the former case than in the latter. The coils in the first case are charged with similar free electricity, and the electrodynamic attraction is weakened by the electrostatic repulsion; in the latter case both actions add themselves, because the electrostatic charges of both coils are dissimilar.

That the currents of radiant electrode matter nevertheless represent actual electric currents is shown by their electromagnetic behaviour, which follows the same laws as the action of galvanic currents. *The mutual repulsion of two currents of radiant electrode matter can only hold as a sure proof that the electric current is caused by the transport of particles electrically charged, and that we have here the case of an electrical convection of a molecular conductor* analogous to that electrical convection of solid conductors which, as the beautiful experiments of Prof. Rowland show, is, electrodynamically considered,

* Poggendorff's *Annalen*, cxlix.

equivalent to the flow of electricity in the conductors themselves.

It can scarcely be doubted, moreover, that the same laws will hold for the convection of molecular conductors as for that of solid conductors. Each particle of the electrode charged with statical electricity which is in progressive motion will behave in the same way towards a magnetic pole as a positive electrical current flowing in the same direction as the positively charged particles, or in the opposite direction to the negatively charged particles. Every electrical particle which traverses a certain path represents to us in reality an "*elementary current*," which up to the present we have used as a mathematical magnitude in our electrodynamical calculations.

Since, as we have already seen, the particles of the electrode are negatively electrical in the rarefied space and move from the negative pole, the action of the current caused by molecular convection is the same as that which would be exerted on a magnetic pole by a positively electrical current flowing in the opposite direction to the motion of the negatively charged particles, that is, from the positive to the negative pole.

I firmly believe, too, that the laws here mentioned can be verified by experiment. For example, an electrified current of steam passing through a tube must deflect a magnetic needle in a way which results from the above consideration. I hope shortly to be able to carry out experiments in this direction, and I will only mention here that I am confirmed in my conviction of the correctness of the above view by an experiment of Mr. Donato Tomasi*, who magnetized an iron cylinder by passing a current of steam, at a pressure of 5 to 6 atmospheres, through a copper tube of 2 to 3 mm. diameter, coiled spirally round the cylinder.

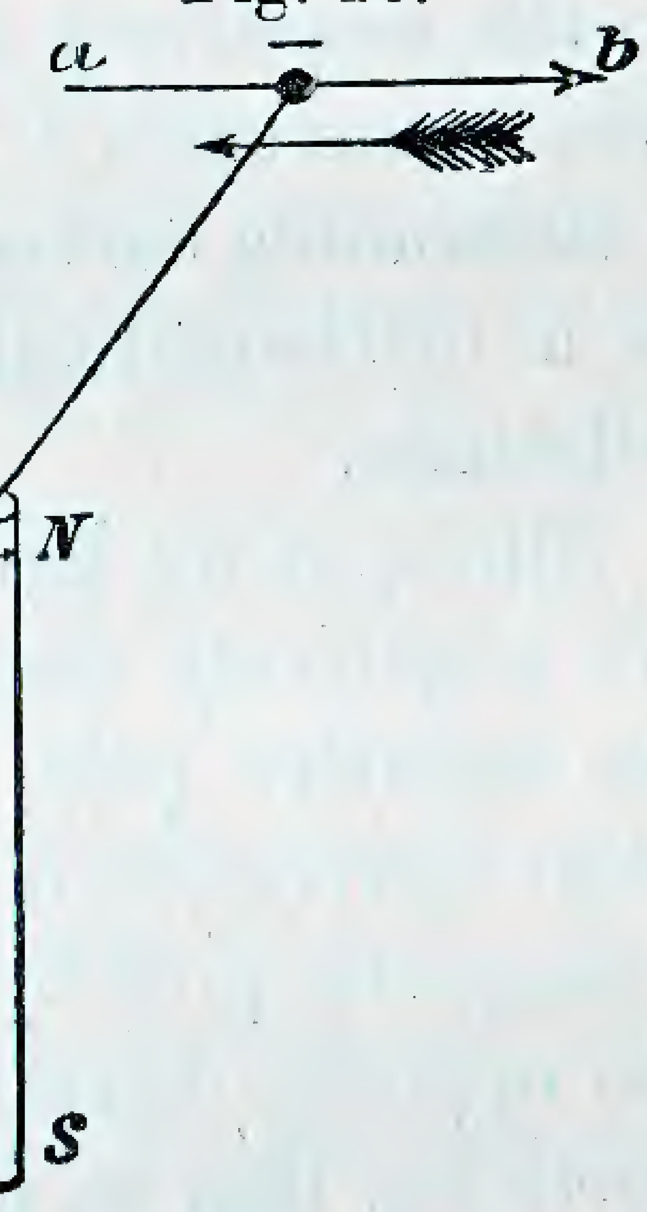
In a notice relative to this in the *Annalen*, Poggendorff remarks :—"In order that this experiment may succeed, however, the conditions must probably have been fulfilled which Faraday has stated to be necessary for the proper electrification of the current of steam."

* Poggendorff's *Annalen*, clv. p. 176.

I consider it very probable that Mr. Tomasi observed the electrical convection of molecular conductors.

Let us suppose a plane through the direction of motion $a\ b$ (fig. 16) of the negatively electrical electrode particle and the pole of the magnet N (let it be the plane of the paper), then the particle during its motion represents to us a positive elementary current in the opposite direction, which is given by the arrow below, and the interaction between the elementary current and the north pole must be measured analogous to the law of Biot and Savart by a couple of forces which are perpendicular to the plane $a\ b\ N$, and the intensity of which is inversely as the square of the distance between them as well as directly proportional to the sine of the angle which the momentary direction of motion $a\ b$ forms with the polar direction, the strength of the magnetic pole, the quantity of electricity, and the velocity of its motion.

Fig. 16.



From Ampère's rule it can further be deduced to which side of the plane chosen ($a\ b\ N$) the particle will be deflected. If the pole is north magnetic the electrode particle will be deflected to the right for an observer looking towards the pole and swimming with the imaginary positive current.

On the other hand, if the observer of the north pole moves in the same direction as the electrode particle, the latter will be deflected to the left.

As, moreover, for a finite magnet the tangents to the magnetic curve, which pass through the electrode particle, represent the direction towards the pole, the force which deflects the particle is perpendicular to the plane which can be drawn through the direction of motion of the particle and the magnetic curve of its transitory position at the moment of observation.

All interactions between the magnet and a current of electrode matter can be explained and predicted by the laws of electrical convection of molecular motion with the aid of Ampère's rule.

Some simple cases are here discussed.

1. The pole of the magnet n and the particle of the electrode m, the latter moving to the right with a very great velocity in the direction of the arrow, are both in the plane of the paper. The pole imparts a small velocity to the particle under the plane of the paper or on the left side of the observer who sits on the particle of the electrode and looks towards the n pole. The particle will move with the resultant velocity $m\,r$ under the plane of the paper, and will diverge the more from the original direction the stronger the magnetic action and the smaller the velocity with which the particle is projected from the electrode. With a south pole the direction of motion falls in front of the plane of the paper.

Fig. 17.

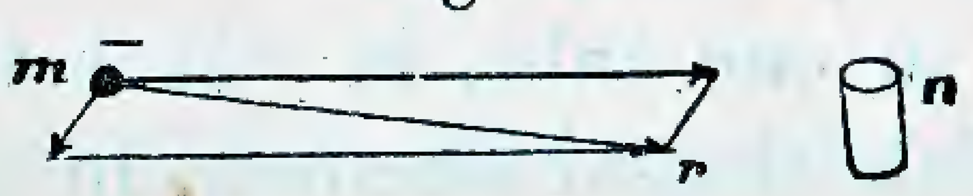
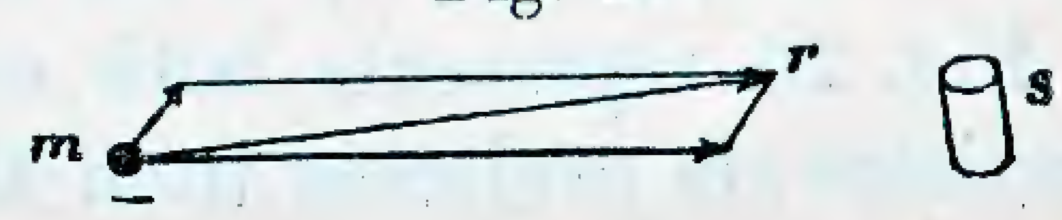


Fig. 18.



2. The pole of the magnet N and a section of the tube from which the particles are issuing in a direction normal to it, are in the plane of the paper. Each particle receives a deflection

Fig. 19.

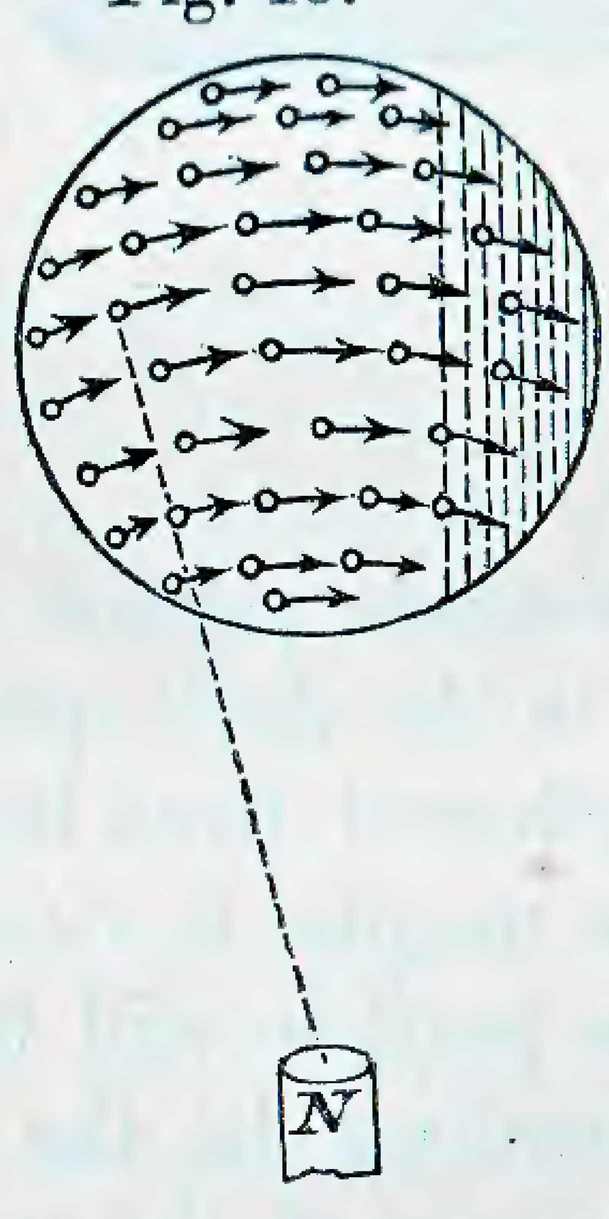
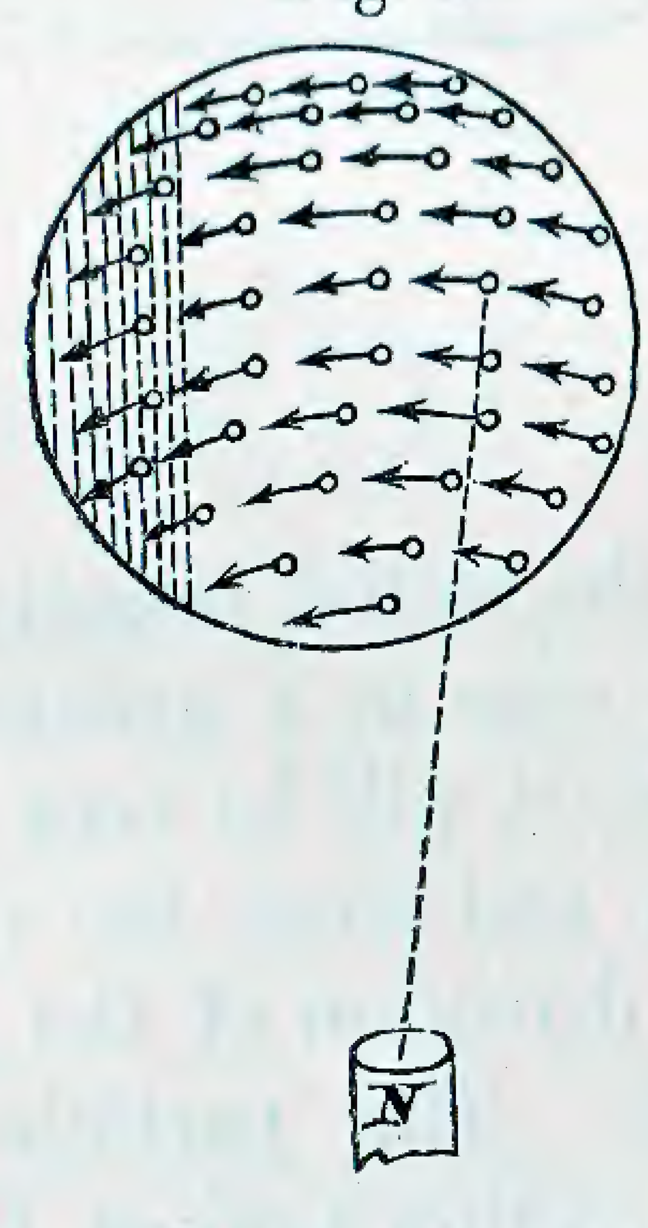


Fig. 20.



in the direction of the small arrows; the light, therefore, is displaced to one side. In fig. 20 the particles move normally under the plane of the paper, and therefore invert the directions of their motion. With a south pole the phenomena are inverted in both cases.

3. From what has been said, the following figures are

easily intelligible. The action of both poles imparts to the particle of the electrode in the first case a resultant velocity *m r* downwards, in the second upwards. Thus the particles

Fig. 21.

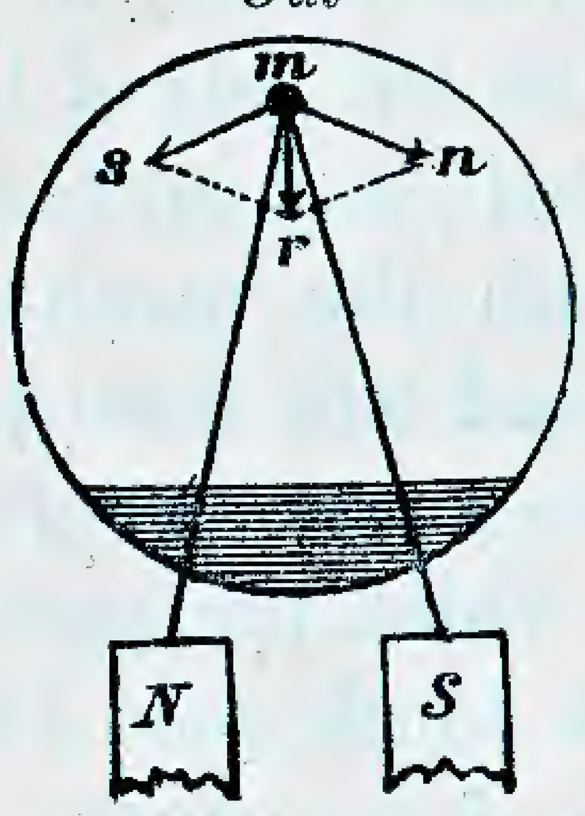
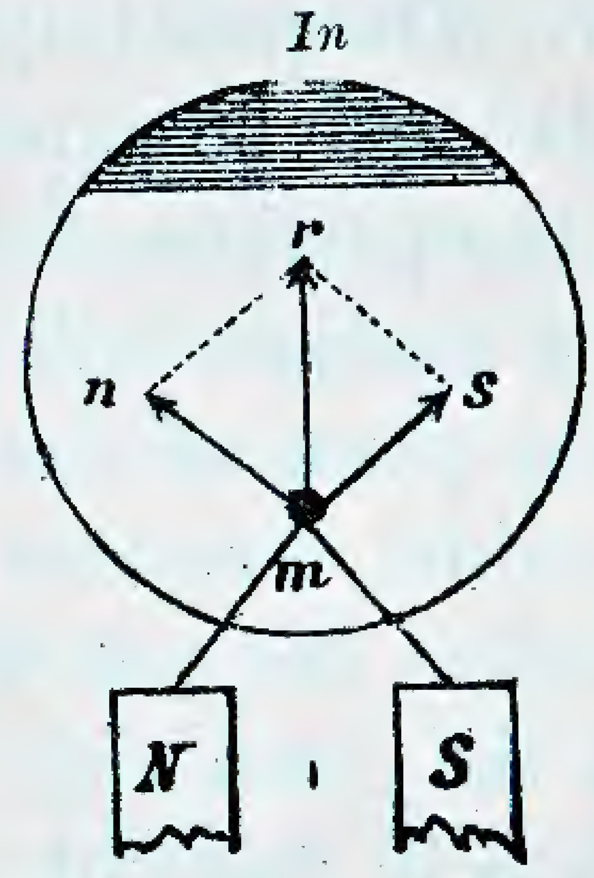


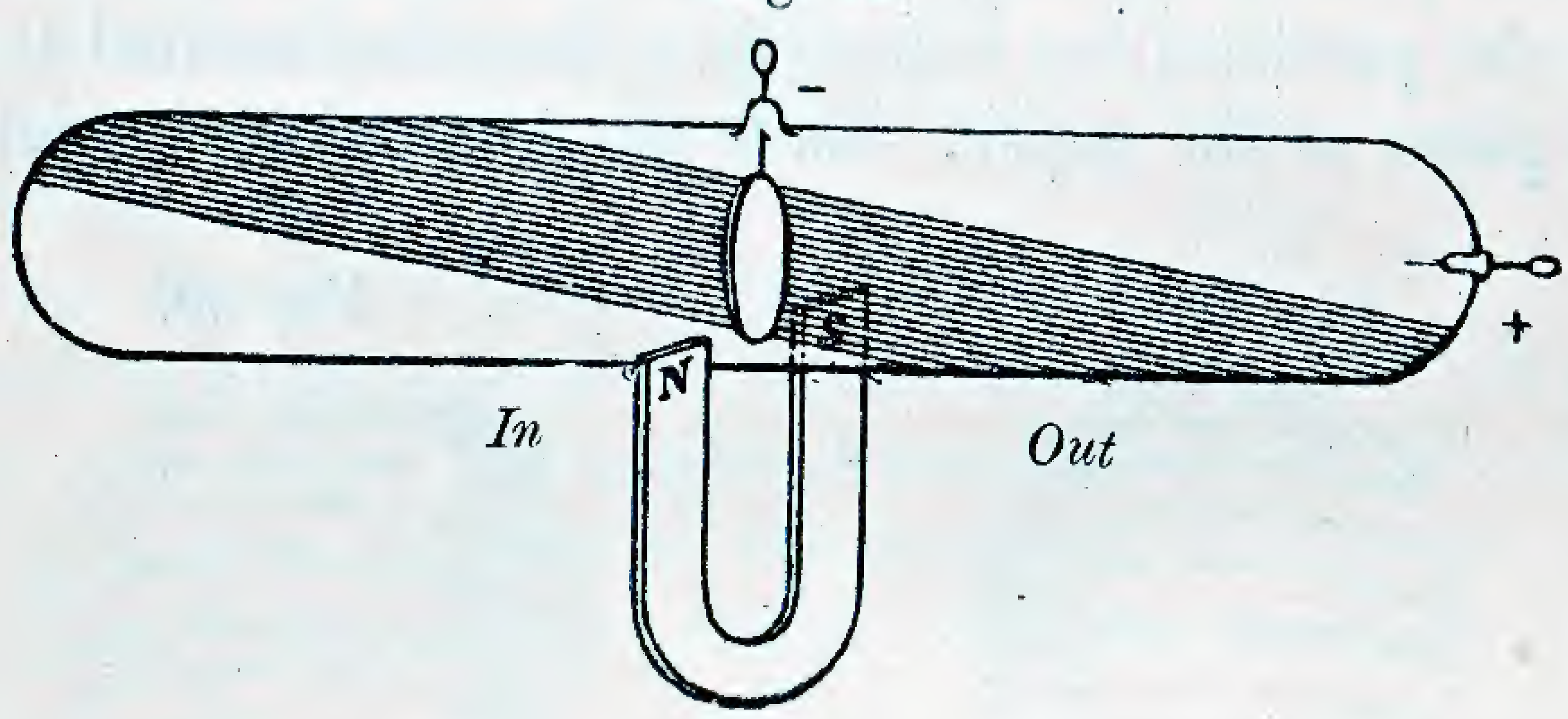
Fig. 22.



are diverted from their original direction of motion in the first case downwards, in the second upwards.

Fig. 23 represents both cases in one tube, in which the particles are projected from the plate-shaped electrode in opposite directions.

Fig. 23.



4. If the initial velocity of the electrode particle is small, as is the case at a greater pressure in the dark space of the *glow-light*, it will be very strongly deflected from its original direction, and since the action of the magnet is a continuous one, the direction of the path of the particle will be always changing. The particle moves according to the position of its direction against the lines of force of the magnet in curves of a simple or double curvature. In fig. 24 the particle m is projected in a direction ma at right angles to the line of force mN, and rotates in the direction of the molecular current of the pole, so that the line of rotation is perpendicular to the line of force. If the initial velocity forms an acute

or obtuse angle with the line of force, the direction of the rotation remains the same; but the plane of rotation changes

Fig. 24.

Fig. 25.

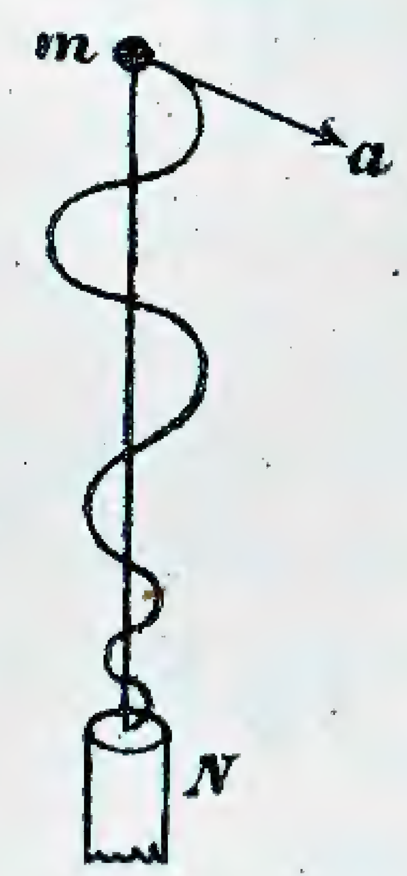
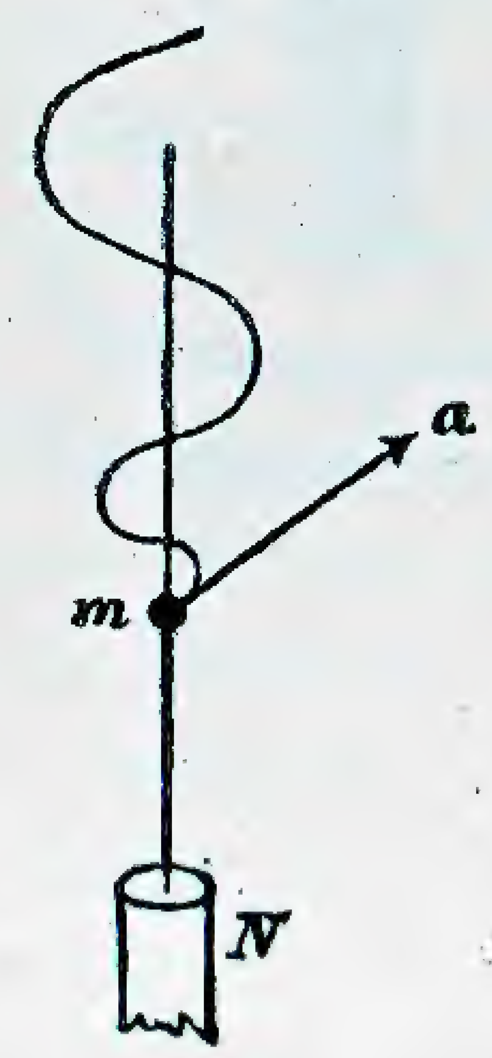


Fig. 26.



continuously, and a path of double curvature is formed, which, on account of increasing magnetic action, is more strongly curved towards the bottom.

5. From a pointed electrode the particles are projected in divergent directions, and on approaching a north pole wind themselves about a cone whose apex is turned towards the north pole, and whose axis coincides with the line of force of the point-shaped electrode. In this is to be found the explanation of the beautiful phenomena in the glow-light, which Prof. Hittorf obtains with the aid of strong magnets. I will here give the drawing of his experiments, which represent the three cases discussed above.

The wire-shaped electrode is surrounded as far as the last section with a glass tube and in fig. 27 (p. 272) is perpendicular to the vertical line of force, therefore in the middle of a circular luminous appearance. If the magnet is very strong, the cone of light contracts to one line, and the rotation of the luminous particles can no longer be distinguished.

Since only a few rays diverge from the last section of the electrode, the spiral turns in the upper and lower parts of the cone of light can scarcely be seen. On the other hand, the convolutions appear very beautiful and distinct if the pencil of rays forms an acute or obtuse angle with the line of force, as is shown in figs. 28 and 29.

Fig. 27.

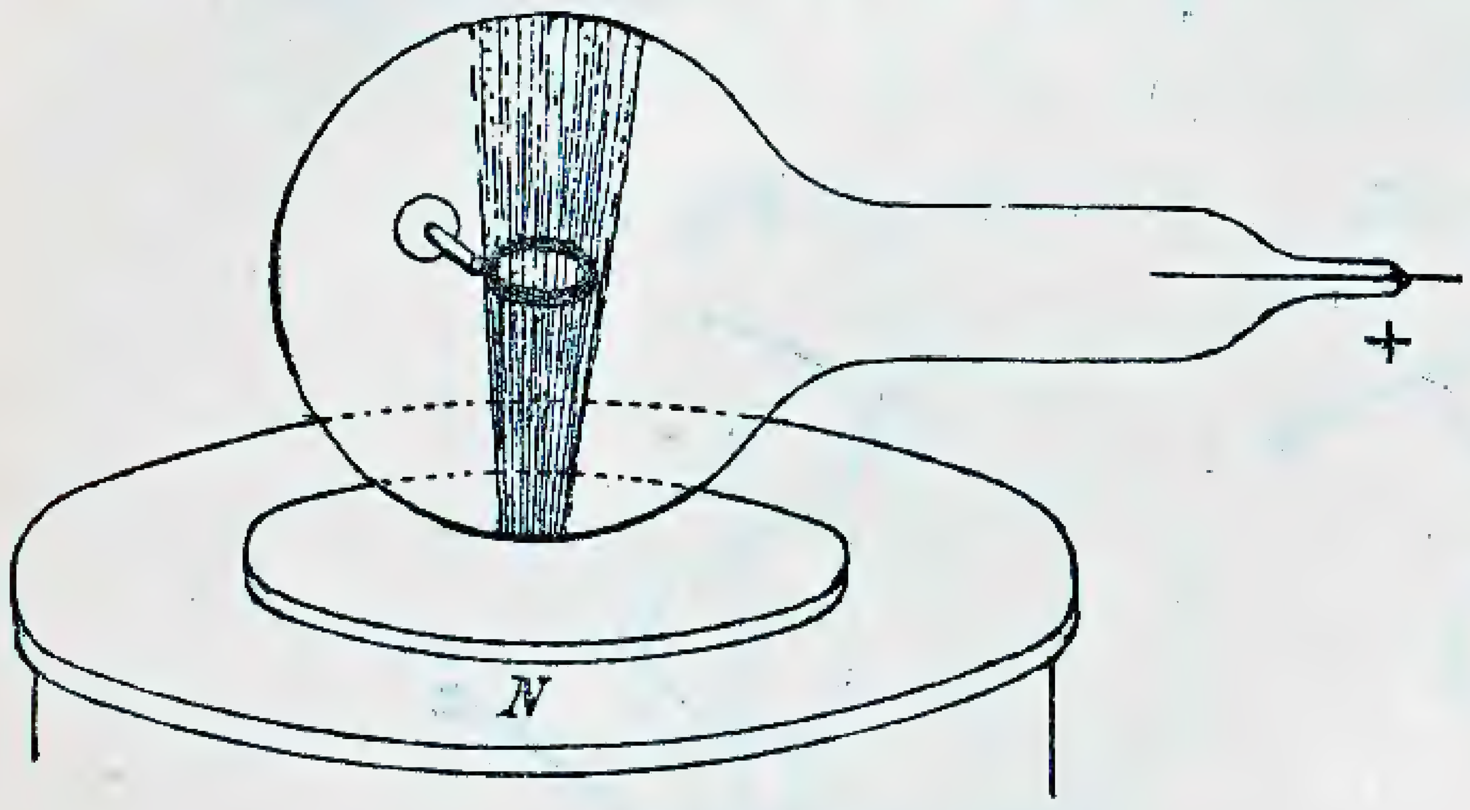


Fig. 28.

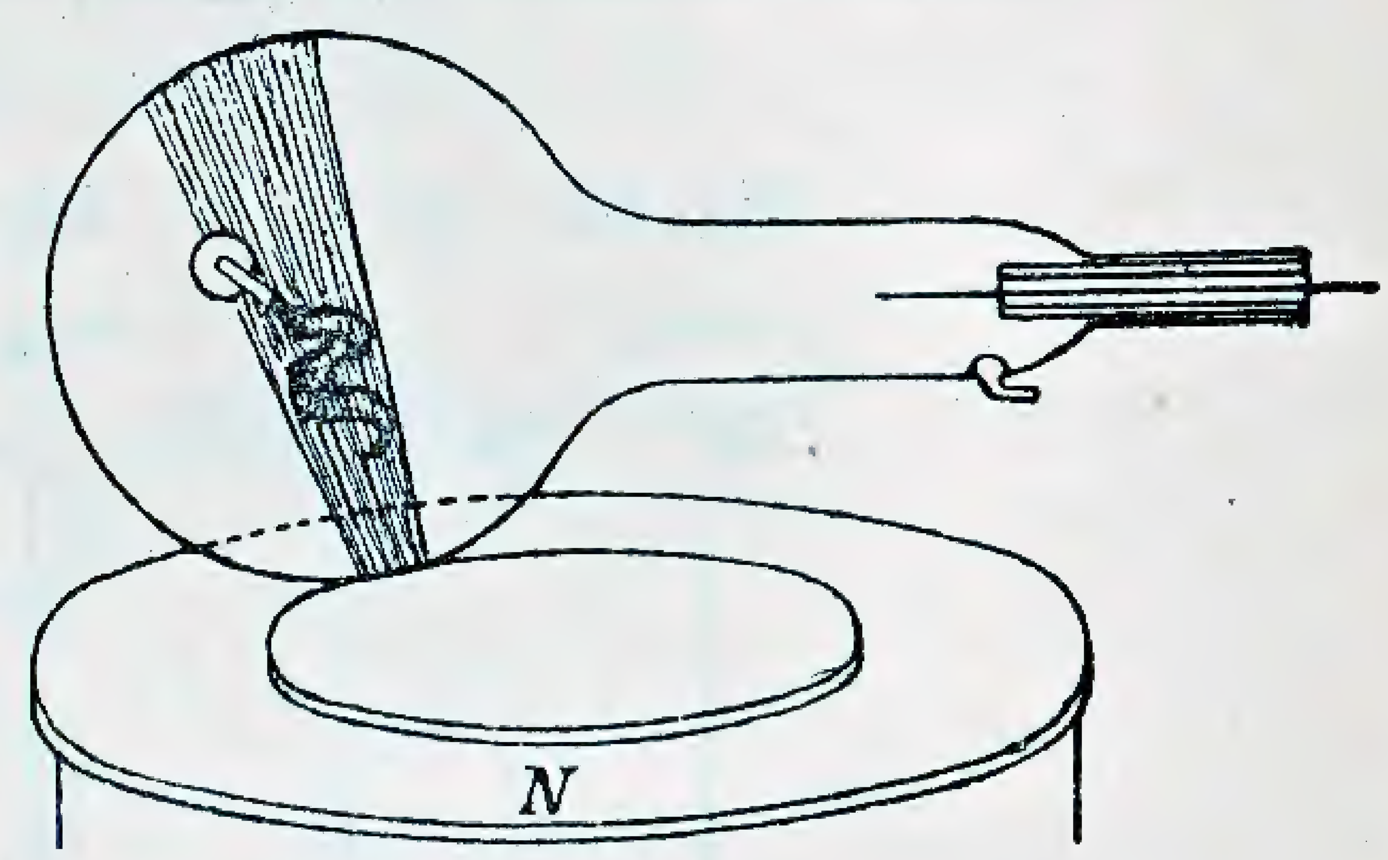
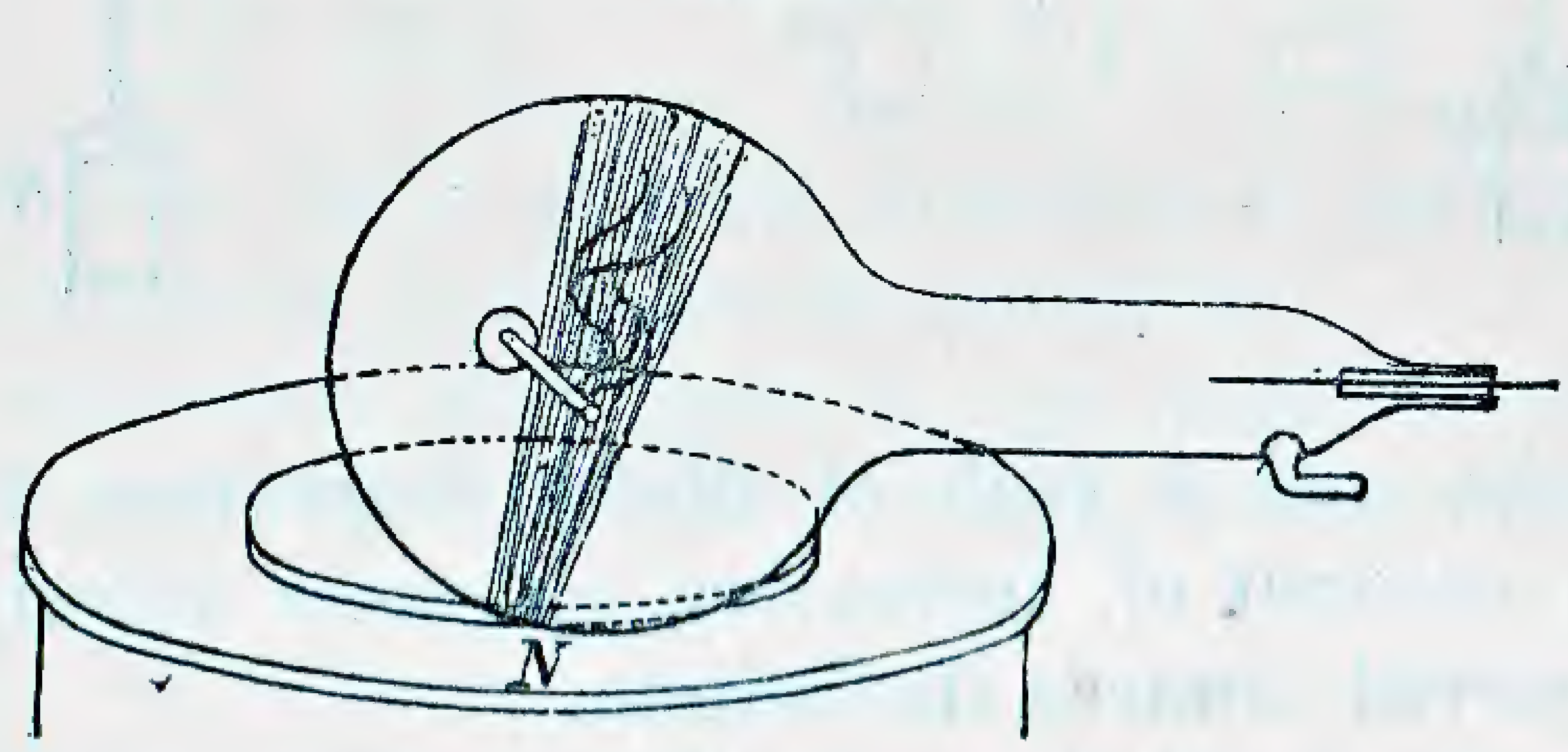


Fig. 29.



6. The magnetic surfaces of the glow-light observed by Plücker can be just as easily explained, by which is understood those surfaces to which the glow-light is spread out

Fig. 30.

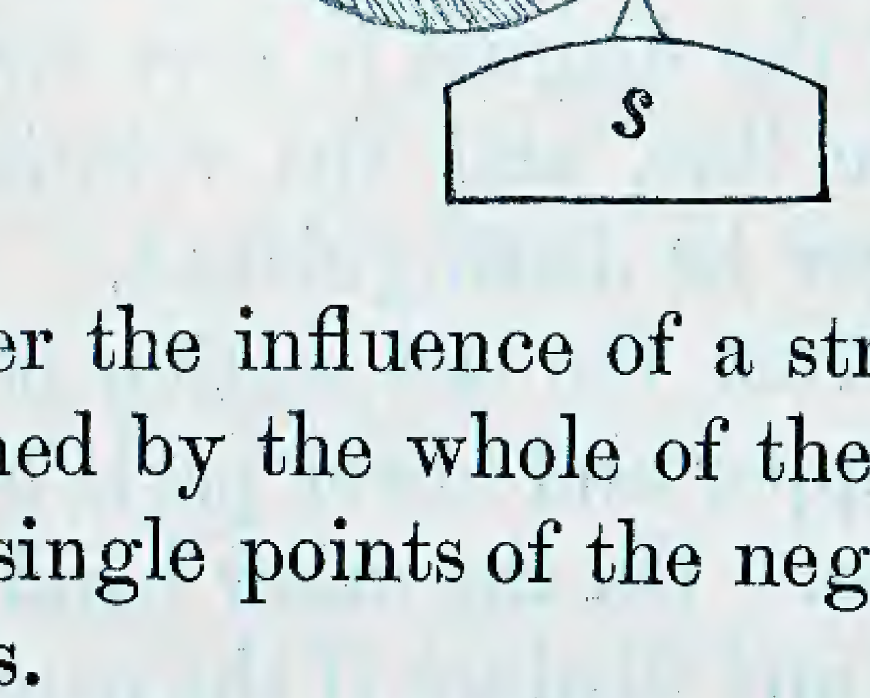
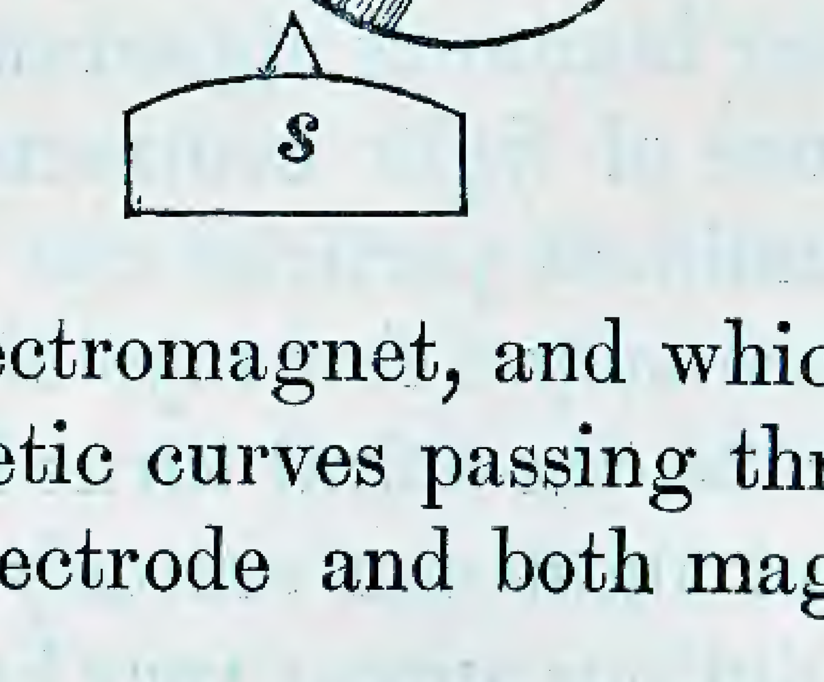


Fig. 31.



under the influence of a strong electromagnet, and which are formed by the whole of the magnetic curves passing through the single points of the negative electrode and both magnetic poles.

Both poles and the negative electrode lie in the plane of the paper. The particles emerge from the wire-shaped

electrode radially in all directions perpendicular to the axis.

Those particles which are emitted from the wire upwards or downwards perpendicular to the plane of the paper are perpendicular to the lines of force which pass through the electrode. These particles must therefore rotate about the line of force in very small circles in a corresponding direction to the molecular currents of both poles. All other particles which emerge from the electrode, obliquely to the plane of the paper or in it, form obtuse angles with the lines of force and must therefore revolve spirally about the latter towards the pole and form a surface of light in the plane of the paper.

Thus all phenomena which are shown by radiant electrode matter as well as by the glow-light under the influence of a magnet can be completely explained by those laws which have been experimentally determined for the electrical convection of material conductors, and by induction have been extended by me to molecular electrode particles also. The solution of this problem was rendered feasible by the possibility of determining the direction of motion of the particles of the electrode.

These laws of electrical convection do not, however, appear to apply to the positive brush-light, and the view that the electric current is caused by the motion of the electricity in the column of gas, just as in a stationary solid conductor, appears to be justified by the behaviour of the positive brush-light. Just as in solid conductors, the molecules which produce the motion of heat allow a passage to the current without changing their relative positions of stability, so, too, in gases of a certain density the electricity appears to discharge itself from section to section without altering thereby either the uniformity of their molecular motion or other oscillatory motions.

The positive brush-light behaves therefore towards the magnet like a very easily flexible wire which is conveying a positive current flowing in the same direction as the column of air. If the brush-light be stratified the stratifications are compressed by the magnet to that side of the tube indicated by the law of Laplace.

If alternating currents are transmitted, it is easily seen that the negative light collects in Plücker's magnetic surface, and the positive light in an equatorial plane perpendicular to this

surface, and the phenomenon observed by Prof. Reitlinger and v. Urbanitzky is obtained which I call a triple surface (*Dreifächerfläche*), because it shows three surfaces which are perpendicular to one another. On inverting the current the positive surface must appear on the opposite side of Plücker's surface and the treble surface appears to have undergone a rotation of 180° about the wire kathode *.

Phenomena of Motion in Radiant Electrode Matter.

After we have recognized the existence of radiant electrode matter, the explanation of some of the phenomena of motion caused by it in exhausted vessels will offer no difficulty. Mr. Crookes describes some little forms of apparatus, of which the fly-wheels were moved by means of radiant electrode matter in the direction from the negative towards the positive pole. On inverting the current, the direction of the rotation was also reversed.

The sketch fig. 32 represents an electrical radiometer which I have constructed. A small wheel of unblackened mica is suspended on a needle-point by means of a small glass cap, and two flat electrodes are fused excentrically into the glass vessel. To obtain a stronger action the electrodes were bent cylindrically, so that their focal line fell on about the middle of a wing when the latter was between the two electrodes.

Fig. 33 represents the section of the apparatus : the small wheel revolves in the direction of the motion of radiant electrode matter, from the negative towards the positive pole.

Prof. F. Zöllner describes an experiment in the third paper of his "*Untersuchungen über die Bewegungen strahlender und bestrahlter Körper*," which Geissler communicated at the last *Naturforscherversammlung* in Hamburg, and which he himself repeated with equal success †. Two platinum wires were fused in as electrodes, and the movable cross consisted of unblackened mica laminæ. If the induced current of a small Ruhmkorff's apparatus were passed through the vessel at a tension of 1 mm., the cross rotated always in such a direction "as corresponds

* *Wien. Akad. Anzeiger*, 1877, no. 10.

† Poggendorff's *Annalen*, clx. p. 464.

to an emission of material particles from the *positive* electrode. On inverting the current, the direction of rotation of the cross changes."

Fig. 32.

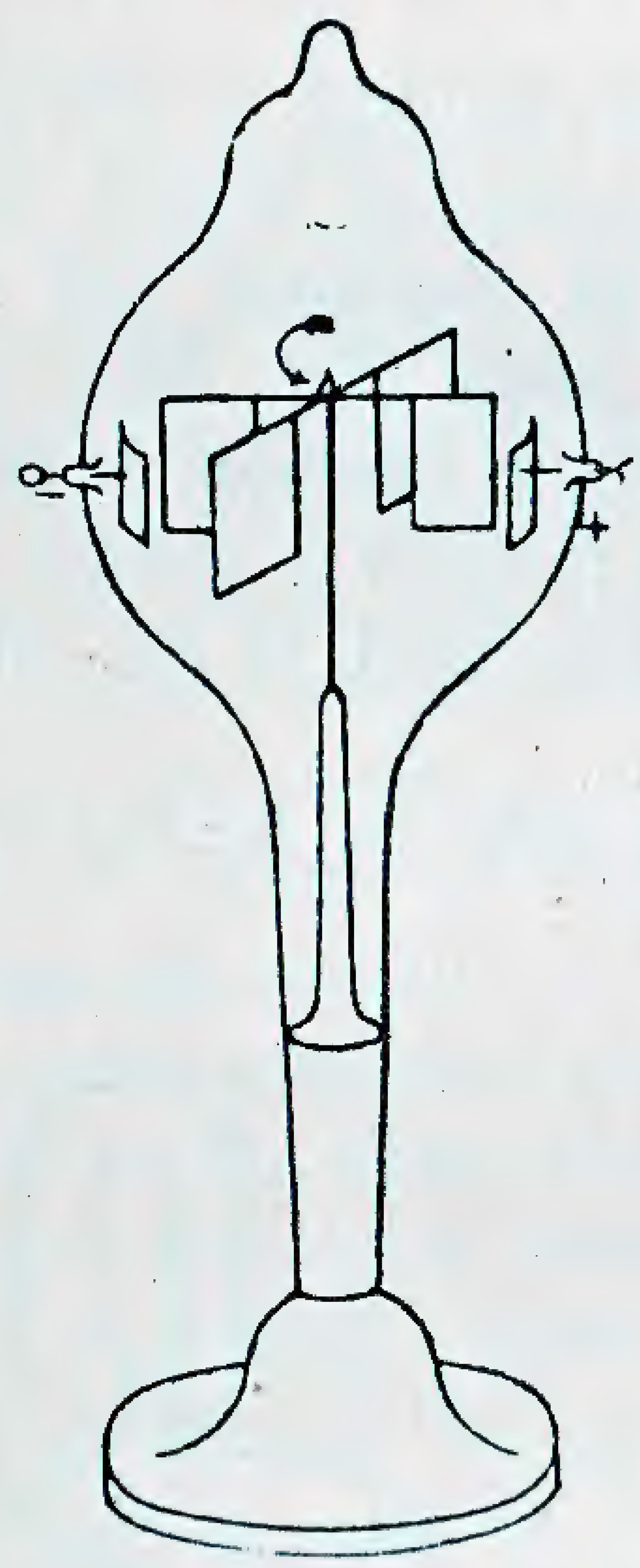


Fig. 34.

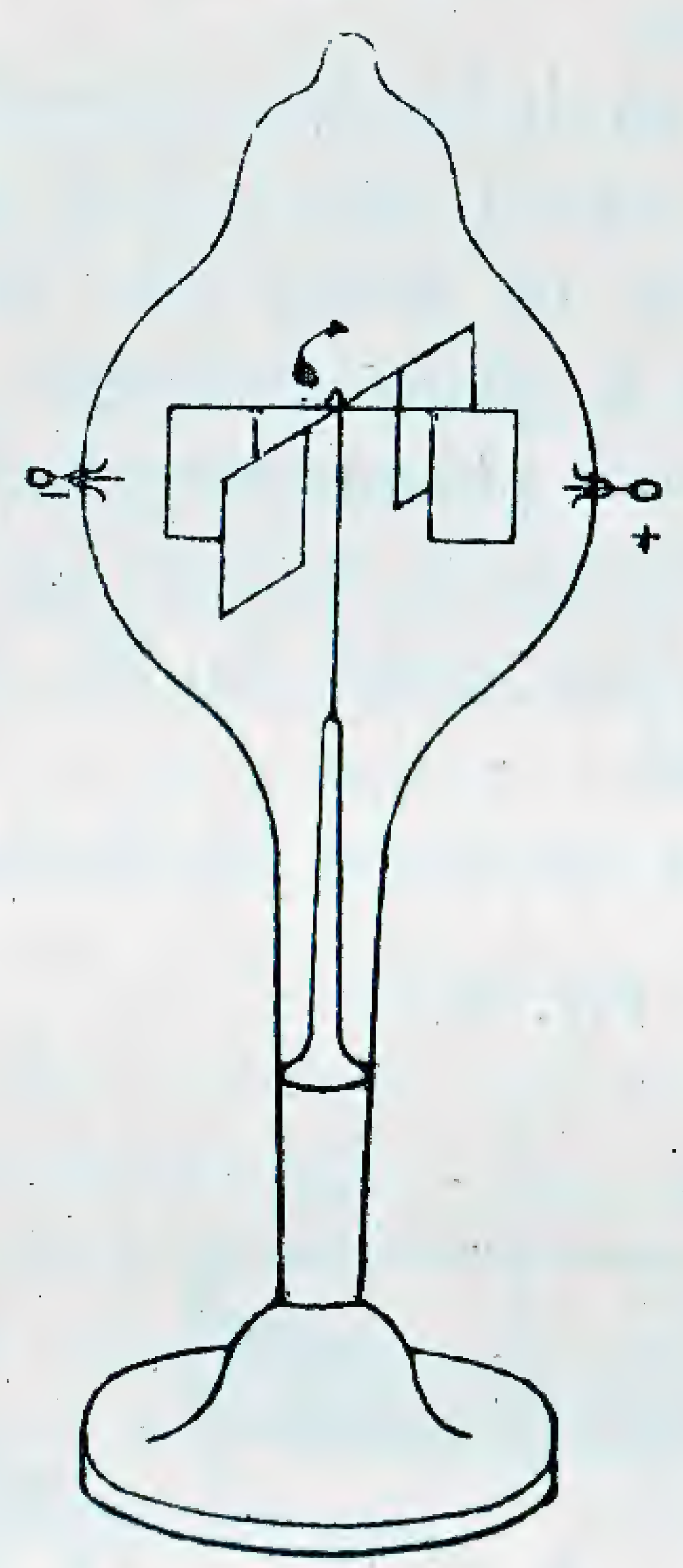


Fig. 33.

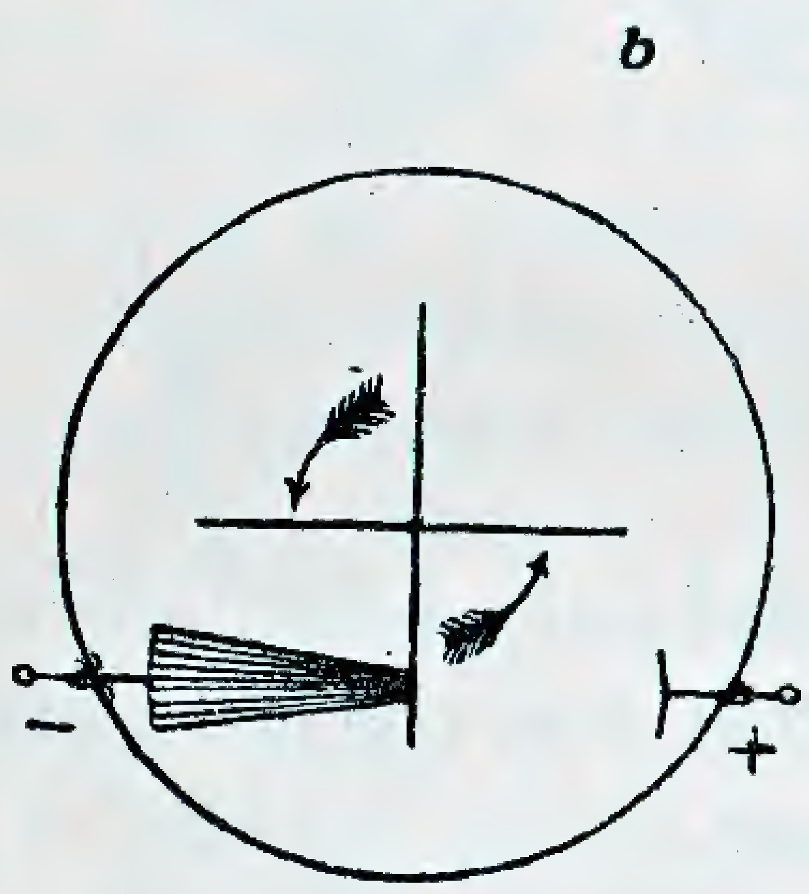
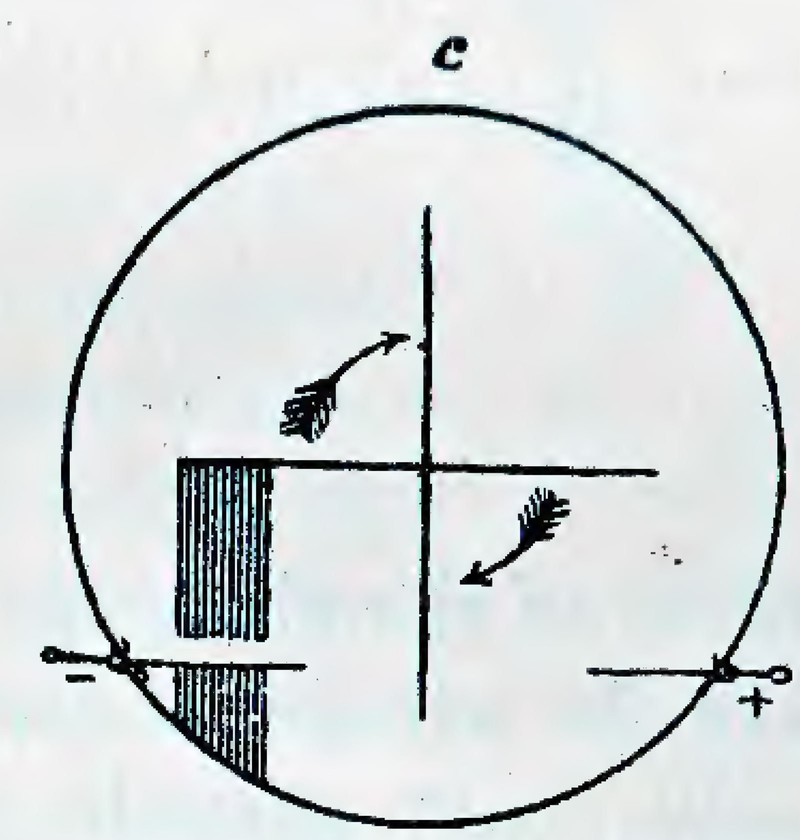


Fig. 35.



It was of great interest to me to determine whether this rotation in the direction of the emission of the particles from the positive electrode also took place at a pressure at which the radiant electrode matter appears. I made the experiment with a radiometer represented in fig. 34, which is furnished with two wire electrodes. At a pressure of 0·03 mm. the little wheel revolved in a direction opposite to that in which it would have rotated with flat electrodes.

The question now arises: Are the particles emitted from the positive or negative electrode, and how is that inversion of the direction of rotation to be explained?

This question is solved by the following very simple experiment.

If an induction-current be passed through a cylindrical glass vessel into which a long wire reaches almost to the middle, on using this as a negative electrode the vessel shows a phosphorescent equatorial zone (fig. 36), which luminous phenomenon assumes an oblique position, as regards the electrodes, as soon as a horseshoe magnet is placed about the glass vessel in the manner represented in fig. 37 and fig. 38.

The luminous equatorial zone can only be formed by the

Fig. 36.

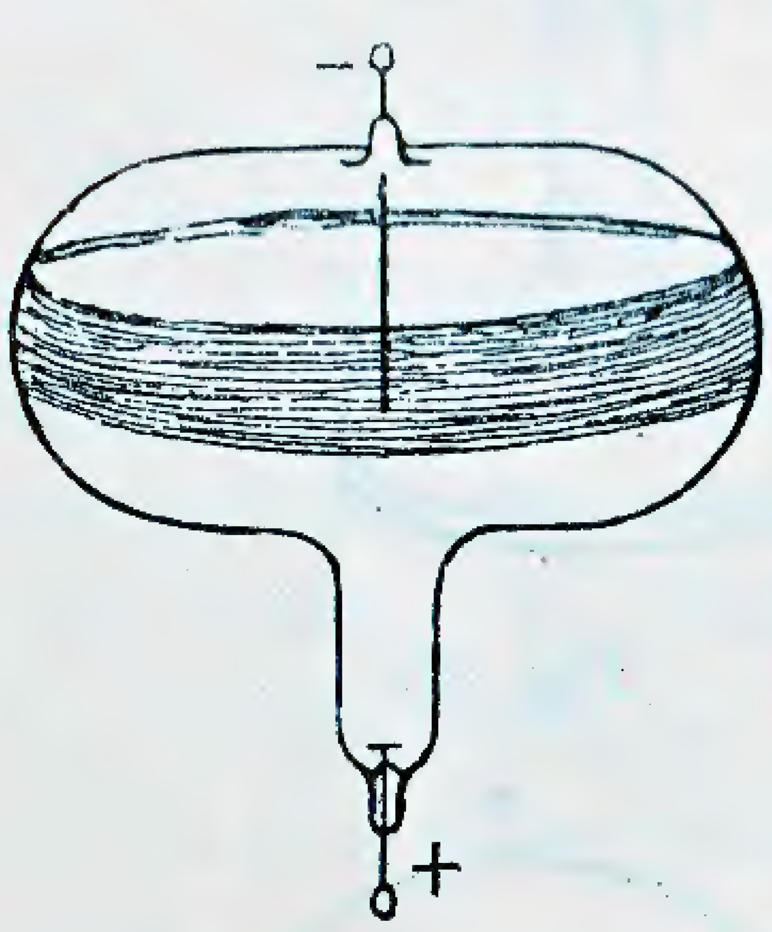


Fig. 37.

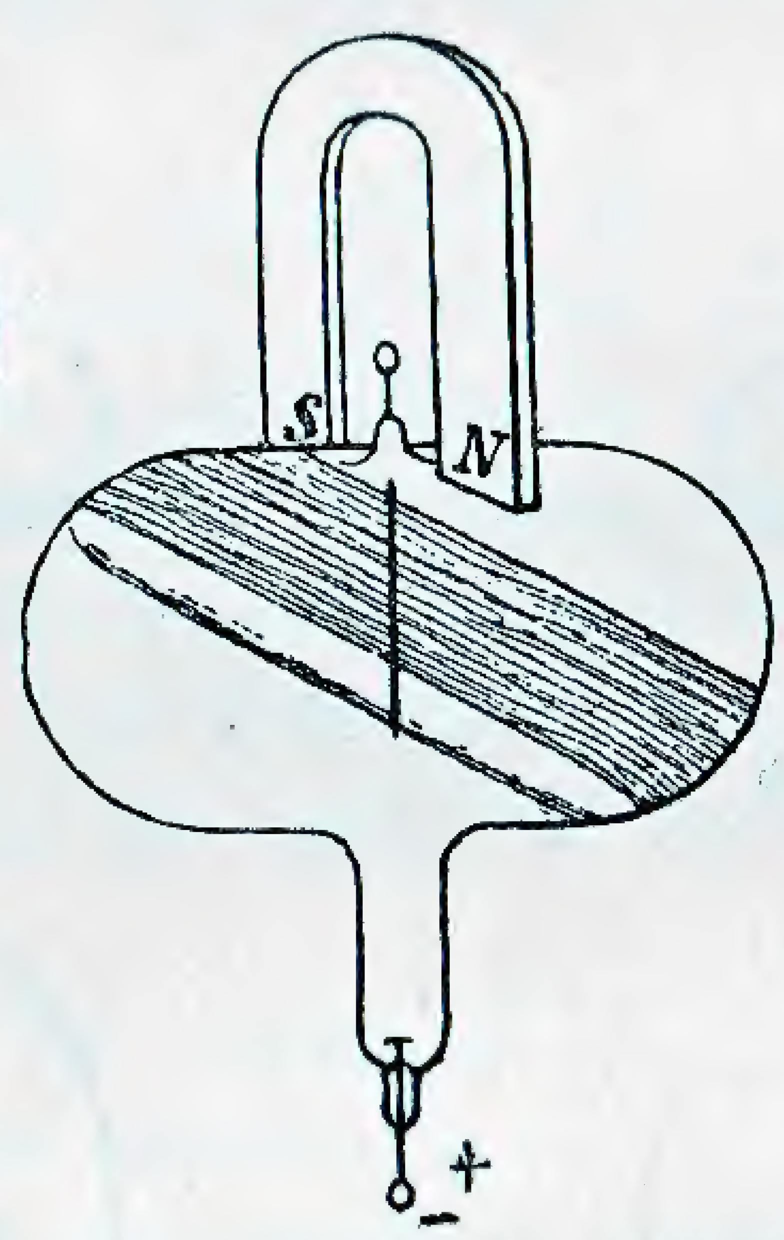
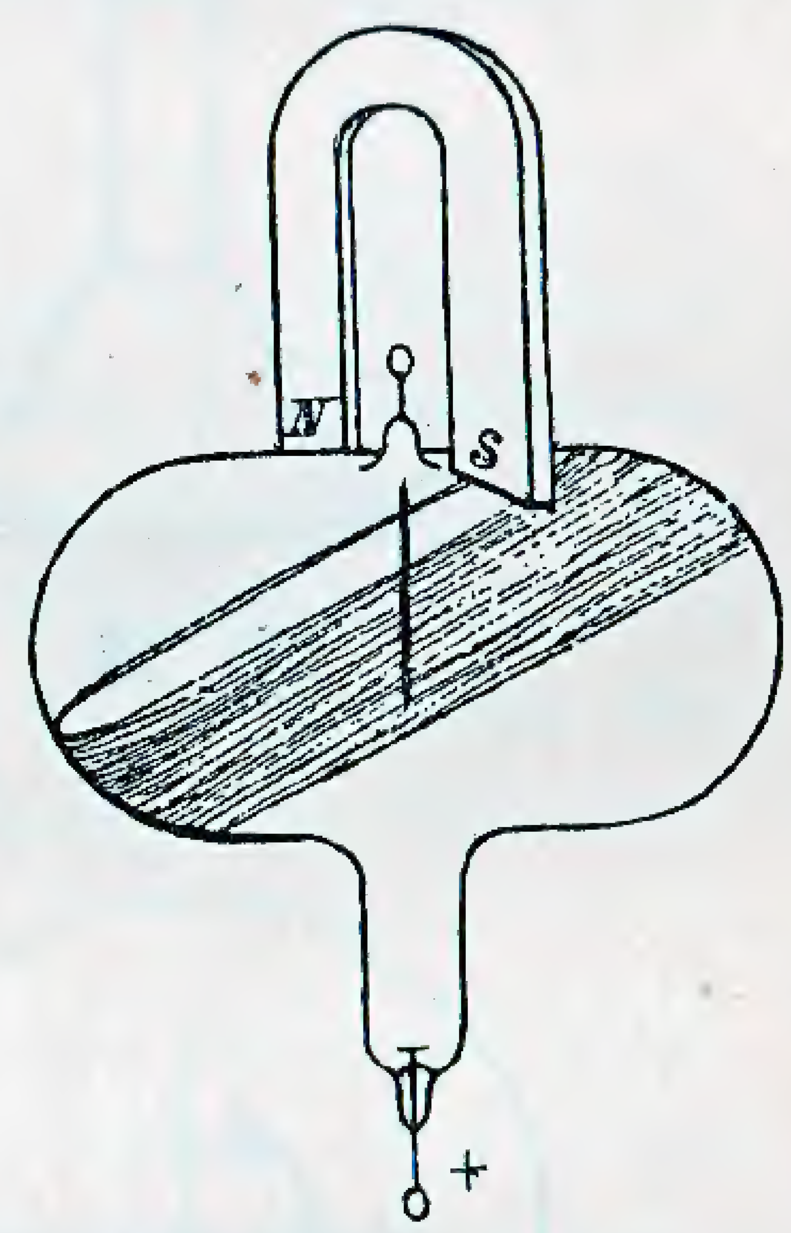


Fig. 38.



particles of the electrode being emitted perpendicularly to the axis of the wire in all directions. That, too, the last section of the wire emits particles perpendicular to the surface is self-evident, only their number is very small in proportion with those thrown off sideways.

It is now easy to understand why, with the same direction of current, the small wheel in the radiometer with wire electrodes turns in the opposite direction to that with plate electrodes. It is at once evident from the sketch, fig. 35, that the lateral emission of the wire must turn the wheel in the opposite direction.

At a very high degree of rarefaction (0·01 mm.) the wheel

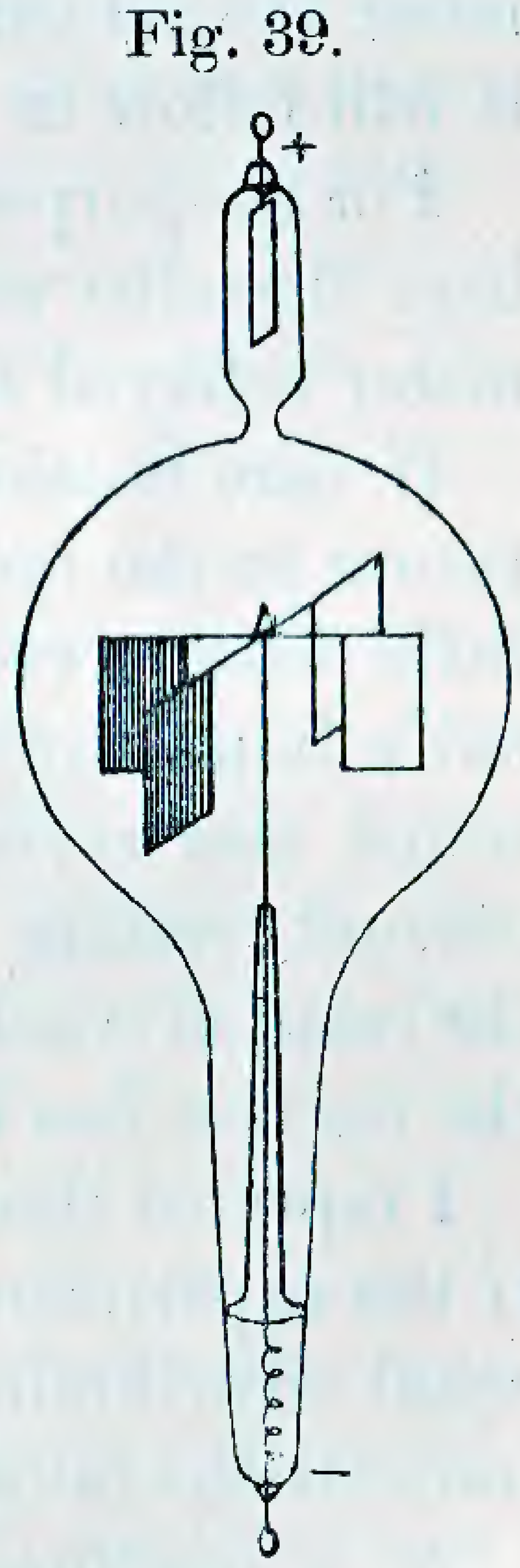
turns round and rotates in the direction of the emission of particles, from the negative towards the positive pole. This is explicable by the fact that at this rarefaction the emission of the particles only takes place at the last *cross section* of the wire.

Thus an emission of the particles does not take place at the positive, but only at the negative pole, and always normal to the surface of the kathode.

That the same explanation holds good for the inversion of the direction of rotation at a pressure of 1 mm. is self-evident, since we have seen that at this degree of rarefaction also particles are emitted from the negative electrode which, diffusing into the residual gas, cause it to phosphoresce, and are therefore unable to cause phosphorescence of the glass side.

The phenomena of motion are more complicated in the electrical radiometer described by Mr. Crookes, represented in fig. 39. The cross, which rests by means of an iron cap on a needle-point, consists of four aluminum plates coated on one side with mica, and the needle is connected by means of a wire to the platinum electrode which is used as a negative pole. In the upper part of the vessel a second platinum wire has fused to it an aluminum plate which serves as the positive pole. In the radiometer with which I experimented the upper tube was strongly constricted (to about 3 mm. diameter). If this part were touched with the finger during the passage of an induction-current giving a 4 cm. spark at a pressure 0·03 mm., the luminosity disappeared from the interior of the tube and a discharge of the current took place again as often as the part was left free. This experiment only succeeded when the upper wire was used as a negative pole.

Fig. 39.



Mr. Crookes observed in this apparatus with a position of the poles represented in the sketch a rotation of the cross with the mica sides forwards and at a pressure which "is a little beyond that at which the dark space round the negative pole extends to the sides of the glass bulb." The rotation begins

at a pressure of about 0·05 mm. This motion Mr. Crookes explains in the following manner*:—

"The molecules being driven violently from the pole there should be a recoil of the pole from the molecules, and by arranging an apparatus so as to have the negative pole movable and the body receiving the impact of the radiant matter fixed, this recoil can be rendered sensible."

According to the view of Prof. Hittorf † the mill rotates first of all when the hot glow-rays reach the glass sides of the vessel and heat the parts touched. "It is the thermal radiation of the glass side therefore which first causes a rotation."

Neither explanation, however, is correct. The incorrectness of Hittorf's view is easily proved by warming the glass bulb of such a radiometer by touching it with the hand. The little wheel rotates with the aluminum and not with the mica forwards even when no current is passing. Since this experiment has not yet been explained so far as I know, a note about it will follow in a later part of this paper.

For the purpose of refuting Mr. Crookes's explanation I will here describe some experiments I have made with the radiometer referred to.

If care is taken to provide for equal distribution of temperature in the radiometer at a pressure of about 0·2 mm., the little wheel revolves with the aluminum forwards once or twice immediately after closing the current, then stops, turns round and revolves with the mica forwards as long as the current remains closed. If the current be afterwards broken the rotation continues, and for so much the longer the stronger the current has been.

I repeated this experiment very often with the same success. If the experiments follow one another without waiting for an equal distribution of temperature, the wheel always rotates towards the mica face.

At a continued rarefaction the number of the incipient revolutions towards the aluminum face becomes larger and larger and also the velocity of the rotation after the inversion. If the current be broken the wheel rotates with a violence which I have not observed in the most sensitive radiometers. The individual laminæ can no longer be discriminated.

* Nature, 1879, p. 436.

† Wiedemann's *Annalen*, vii. p. 607 [*vid. supr.* p. 224].

If the pressure is so small that the phosphorescent phenomenon of the glass side is visible, at about 0·04 mm., the wheel only rotates towards the aluminum face and the inversion of the rotation takes place only towards the mica face after breaking the induction-current, and continues for five or six minutes or even longer according to the intensity of the current and duration of its action.

The complete course of these phenomena of motion has not been noticed by Messrs. Hittorf and Crookes, and it has therefore not been easily possible for them to find a correct explanation.

These motions of rotation are regulated by the following causes, opposite in their action :—1. By the emission of radiant electrode matter ; 2. By the motion of heat which the electric current causes in the aluminum plates ; 3. By the radiation of heat from the glass sides.

The reaction of the emitted particles of the electrode must cause a motion of the wheel towards the mica face, according to the principle of the maintenance of the centre of gravity. The same motion must also result from the reaction of molecules of gas striking to and fro on the aluminum side of the wings warmed more strongly by the current. Both forces thus act in one direction.

A third force, acting in the opposite direction to the two first forces, results from the heating of the glass sides by the particles of the electrode striking against them. The glass sides radiate heat towards the interior. The surfaces of the mica and aluminum become warmed, but whereas in the former the heat remains in the highest layer, in the aluminum, on account of its good conducting power for heat, it is transmitted to the lower layers. Hence the surface of the mica becomes warmer than that of the aluminum, and from the reaction of the particles of gas and of the electrode striking to and fro, a motion of the wings takes place towards the aluminum face.

We can easily convince ourselves of this by using a radiometer whose aluminum wings are covered on one side with mica. Fig. 40 on page 281 is the section of such a radiometer. Aluminum is denoted by a dark band. If the glass vessel is warmed by means of the hand or radiant heat

of a hot metal plate, dark heat-rays are absorbed in the glass side and only indirectly reach the wings. The heat-motion of the glass sides is conveyed to the vanes by means of radiation and molecular motion of the gas, and these move for the reason given with the aluminum face forwards.

The above three forces act simultaneously on the vanes so long as the current is closed and can mutually in their actions weaken or entirely annul one another. If the current is closed the heating of the aluminum plate is at first very small, the radiation of the glass sides preponderates and causes an incipient rotation towards the aluminum face. After some time the heating by the current continually becoming greater finally obtains the ascendency, and an inversion of the direction of rotation takes place. After breaking the induction-current a rotation takes place in consequence of this heat-action towards the mica face until the temperature in the plates has become equalized.

On continued rarefaction the resistance to the induced current, thus also the energy of the discharges and heating of the glass sides, becomes larger and larger, on the other hand, the resistance of the air, which retards the motion of the vanes, less, hence the number of the incipient rotations towards the aluminum face and in like manner the velocity of rotation towards the mica face increases on closing and opening the current.

At a very small pressure the radiation of the walls is stronger than the heating of the vanes by the current, the wheel *only* moves towards the aluminum face as long as the current remains closed ; after breaking it the surface of the mica plate becomes colder than that of the aluminum, because in the latter the lower strata can give up their heat rapidly to the upper ones and the wheel must rotate in the opposite direction.

Now theory is only correct if the conclusions to which it leads can be verified by experiments. We will therefore submit the explanation of the radiometric phenomena of motion given to this test, and for the sake of simplicity consider a fixed aluminum cross whose vanes are covered on one side with mica. A cubical surface envelope surrounding the cross is movable about a vertical axis. The sketch fig. 41 repre-

sents the section of this arrangement and of the case ; the black sides of the cross denote aluminum.

At a moderate rarefaction, when the heating of the vanes by the current preponderates, the molecules of gas rebound from the aluminum face with a greater velocity, move with

Fig. 40.

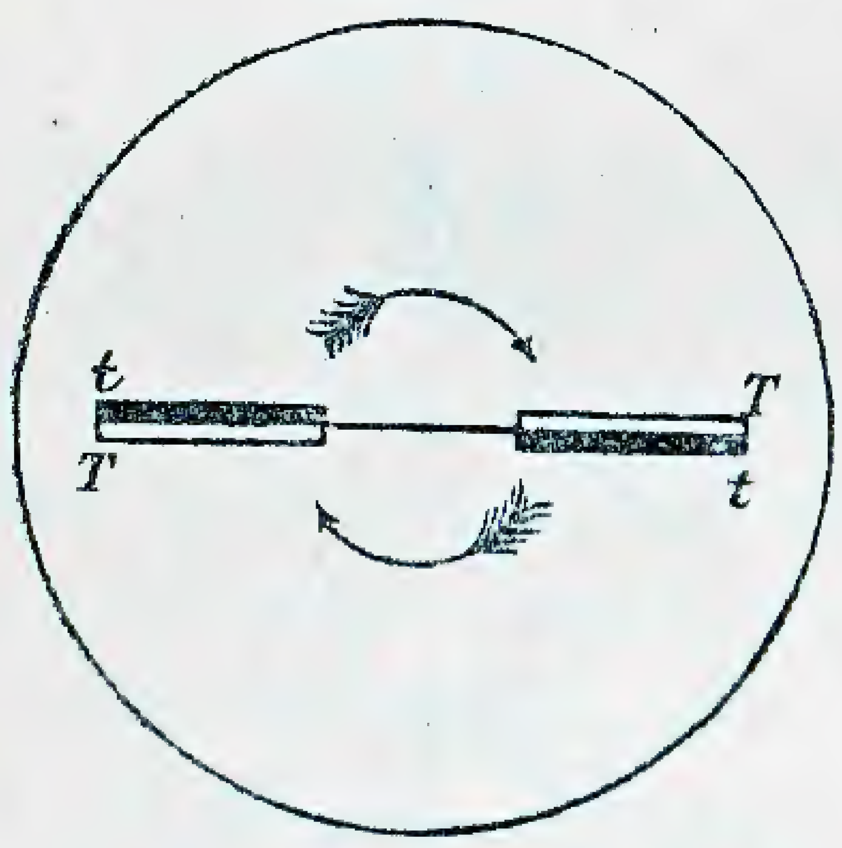
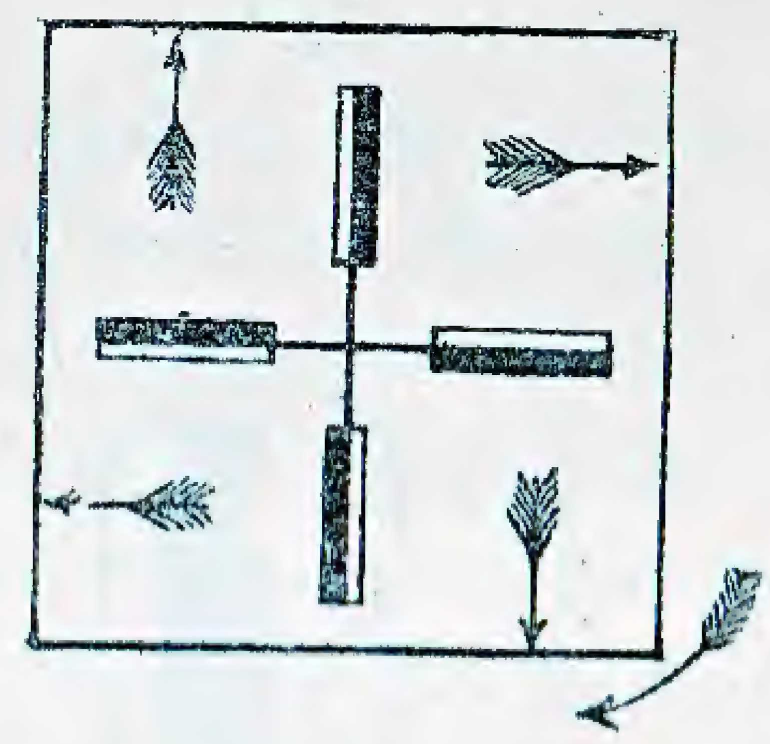


Fig. 41.



the emitted particles of the electrode against the envelope, and give a resultant pressure in the direction of the arrow at about the middle of the quadrant. The same pressures act also in the other quadrants. The direction of rotation of the envelope is seen from the sketch, and is opposite to the direction of rotation of the movable cross.

At a very high degree of rarefaction, a rotation must take place in the opposite direction if the radiation of the envelope preponderate.

This conclusion from the theory of the phenomena of motion here given has been completely verified by experiment. The radiometer which I constructed for this purpose consisted only of two fixed vanes (fig. 42, p. 282), and a glass globe which was movable on a pivot. At a moderate rarefaction the glass globe rotated in that direction of the emitted particles of the electrode which had been previously determined.

At a greater rarefaction, when the glass globe phosphoresced brightly, a rotation took place in the opposite direction, *i. e.* from the mica side of the one vane to the aluminum side of the next following.

In these and other apparatus I have often made the remarkable observation that if they had been very strongly evacuated and not in use for a long time, phenomena occur for some seconds on the passage of the current which otherwise are seen only at a low degree of rarefaction. While the sides phos-

phoresce faintly the interior of the apparatus is filled with a blue mist. After a short time this mist disappears, the atmosphere becomes clearer, and the phosphorescence brighter, corresponding to the high degree of rarefaction. The phenomena of motion are such, too, as are observed at a greater

Fig. 42.

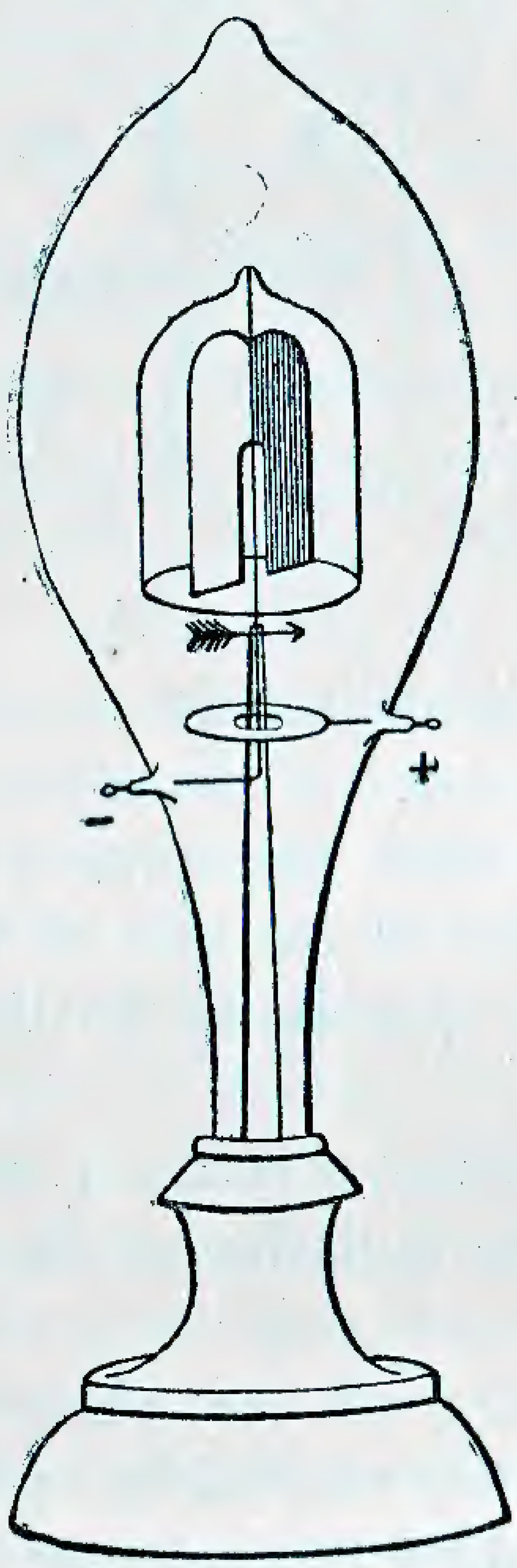
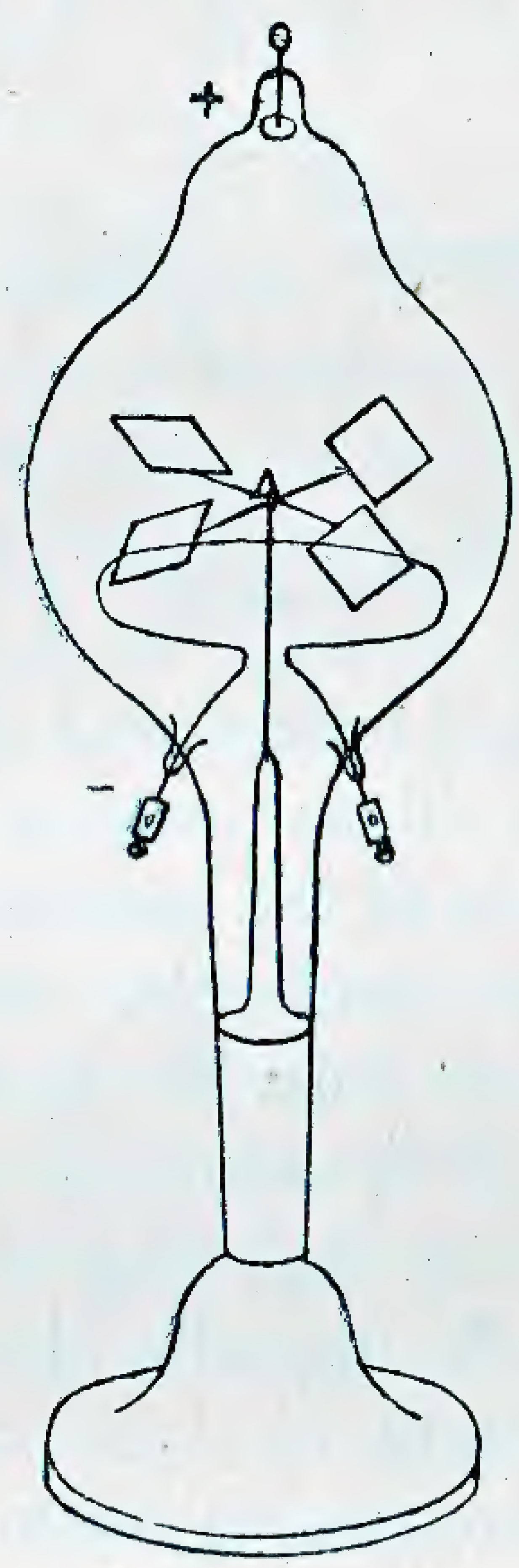


Fig. 43.



pressure. The glass cylinder rotates in the direction of the emission of the particles from the aluminum face, stops after a few revolutions, and afterwards changes its direction of rotation. I explain these changes in pressure in this way, that on the passage of the current the occluded gases are disengaged from the electrodes and somewhat increase the pressure. After some time a portion of the particles charged with statical electricity remains adhering to the glass and is partly absorbed by the positive electrodes, in consequence of which the pressure of the rarefied gas diminishes.

Mr. Crookes also describes in his work a radiometer which Prof. Zöllner had already constructed years before and attempted to explain in the treatise alluded to, *Unter-*

suchungen über die Bewegungen strahlender und bestrahlter Körpen *. The apparatus consists of a movable cross with unblackened mica plates which are inclined towards the horizon as is seen in fig. 43. A ring of platinum wire lying horizontally is placed under the cross and its ends are fused into the glass side in order to be able to pass a galvanic current through it.

Reserving the minuter details of all the experiments which Prof. Zöllner carried out with this apparatus for the next paper, I will only allude here to that experiment which Mr. Crookes, to whom Zöllner's work appears to have remained unknown, repeated with like result and explained incorrectly.

If a galvanic current be passed through the platinum ring at a high degree of rarefaction, "normal" rotation of the wheel takes place; that is, such a rotation as might have been explained according to Zöllner's view by an upward current of air or by a process of emission from the surface of the wire †.

The rotation of the wheel in a normal direction is independent of the direction of the current.

Mr. Crookes also describes this experiment and remarks on it as follows:—"Here, then, is another important fact. Radiant matter in these high vacua is not only excited by the negative pole of an induction-coil, but a hot wire will set it in motion with force sufficient to drive round the sloping vanes" ‡.

Mr. Crookes appears to wish to seek confirmation of this view in the following modification of Zöllner's experiment. His radiometer was furnished with an electrode above the cross (fig. 43). If the platinum ring were used as the negative electrode of an induction-current, the wheel revolved in accordance with an emission of the electrode particles in a normal direction, that is, the same direction as that in which it rotates on the passage of the galvanic current.

We are, however, in no way justified in concluding that *similar effects are due to similar causes*, and so much the less since the induction-current in its passage through the platinum ring cannot alone set the radiant matter in motion; a

* Poggendorff's *Annalen*, clx. p. 460.

† *Tom. cit.* p. 300.

‡ Nature, vol. xx. 1879, p. 436.

heating of the wire by the galvanic current must first take place if the particles are to be emitted.

The investigations which I have made with Zöllner's radiometer lead, in conjunction with the facts observed by him, to the following simple explanation of this experiment.

At a high degree of rarefaction in this radiometer (0·02 mm. mercury pressure), owing to the smaller thermal conductivity of the residual gas, the heating of the wire is greater and consequently the thermal radiation stronger; the latter according to Stefan being proportional to the fourth power of the absolute temperature *. Thus the mica laminæ become more strongly warmed on the side facing the platinum ring than on the opposite side, owing to their low conducting power for heat; and there results from the impact and recoil of the molecules of gas on the more strongly heated face of the laminæ a pressure on their upper surface directed perpendicularly, which must turn the wheel in the direction observed.

Besides the action of radiant heat, this motion is also caused by the thermal conductivity of the gas. By striking against the hot wire, the molecules of gas acquire a greater molecular velocity, and transfer part of their *vis viva* to the vanes. In the first case the motion is caused by a mere *reaction* of the colliding molecules of gas, in the second by a *transfer of vis viva*, by means of impacts of the molecules of gas. Both actions add themselves, since they take place in the same direction, and hence the violent rotation which is here generally noticed.

In order to test the views here advanced as to the cause of the phenomena of motion, I have constructed a new electrical radiometer. Such a one is represented in fig. 44. The pair of semicylindrical vanes of aluminum foil is suspended free to move by means of a brass cap on a steel point; the latter is in connexion with the platinum wire fused into the glass, and is used as the kathode. The anode is above the flywheel in a narrow piece of the tube.

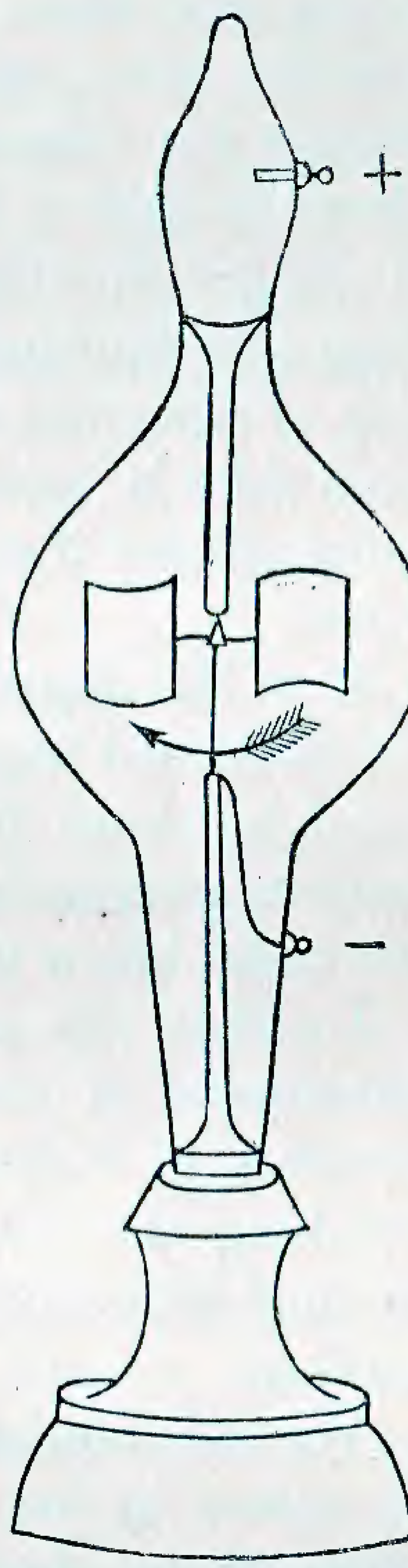
The following phenomena of motion were observed with this radiometer :—

1. At full atmospheric pressure the pair of vanes revolved with the *concave* side forwards, and it was immaterial whether

* *Sitzungsbericht Wien. Akad.* lxxix. p. 391.

they were used as anode or as kathode. If the palm of the hand was placed about the pear-shaped glass vessel, but not in contact with it, the pair of vanes revolved very quickly with the convex side forwards, and still more quickly on touching.

Fig. 44.



2. At a pressure of about 620 mm. the first inversion of direction of the vanes took place, and they rotated with the convex side forwards. The velocity of motion on further rarefaction increased at first, and then decreased until the rotation finally ceased, when a streak of light appeared between the metallic cap and the anode. At about 390 mm. the wheel revolved so quickly that the vanes could no longer be distinguished. The motion was somewhat quicker when the pair of vanes was used as the kathode, and slower when as the anode. At about 140 mm. the motion ceased.

3. At a pressure of about 0·5 mm. a second inversion of direction took place if the pair of vanes served as the kathode, and the wheel surrounded by a glow-light rotated with the concave side forwards. At a further rarefaction, the velocity of motion at first increased and then decreased. At about 0·04 mm. pressure the motion was very quick, and at 0·02 mm. considerably slower. The frictional resistance at the point could often not be overcome, and therefore the beginning of the motion had to be assisted by gentle tapping.

At this rarefaction the following experiment was tried. I allowed the current to discharge itself for 30 to 60 seconds through the radiometer until the vanes began to move towards the concave side. If the current were now broken, the vanes rotated rather quickly about twice in a second, and made about 130 rotations ; this experiment was often repeated with similar results. At a further rarefaction, the number of rotations was always smaller after breaking the current.

4. At a still further rarefaction of about 0·01 mm., when

the glass sides phosphoresce brightly, a *third* inversion of the direction of motion takes place. The pair of vanes turns once more with the convex side forwards. The discharges take place for the most part only at the edges of the aluminum plates, and hence very many luminous figures which rotate with the vanes appear on the sides. As, moreover, the discharges are intermittent, they strike different parts of the glass side during the motion of the vanes, and, on account of the longer duration of the impression of light, the eye sees them simultaneously. The glass vessel shows a very beautiful play of flickering lines of light. The phosphorescence of the glass sides is somewhat more vivid, and the rotation of the vanes quicker if a break of air is interposed in the conducting wires.

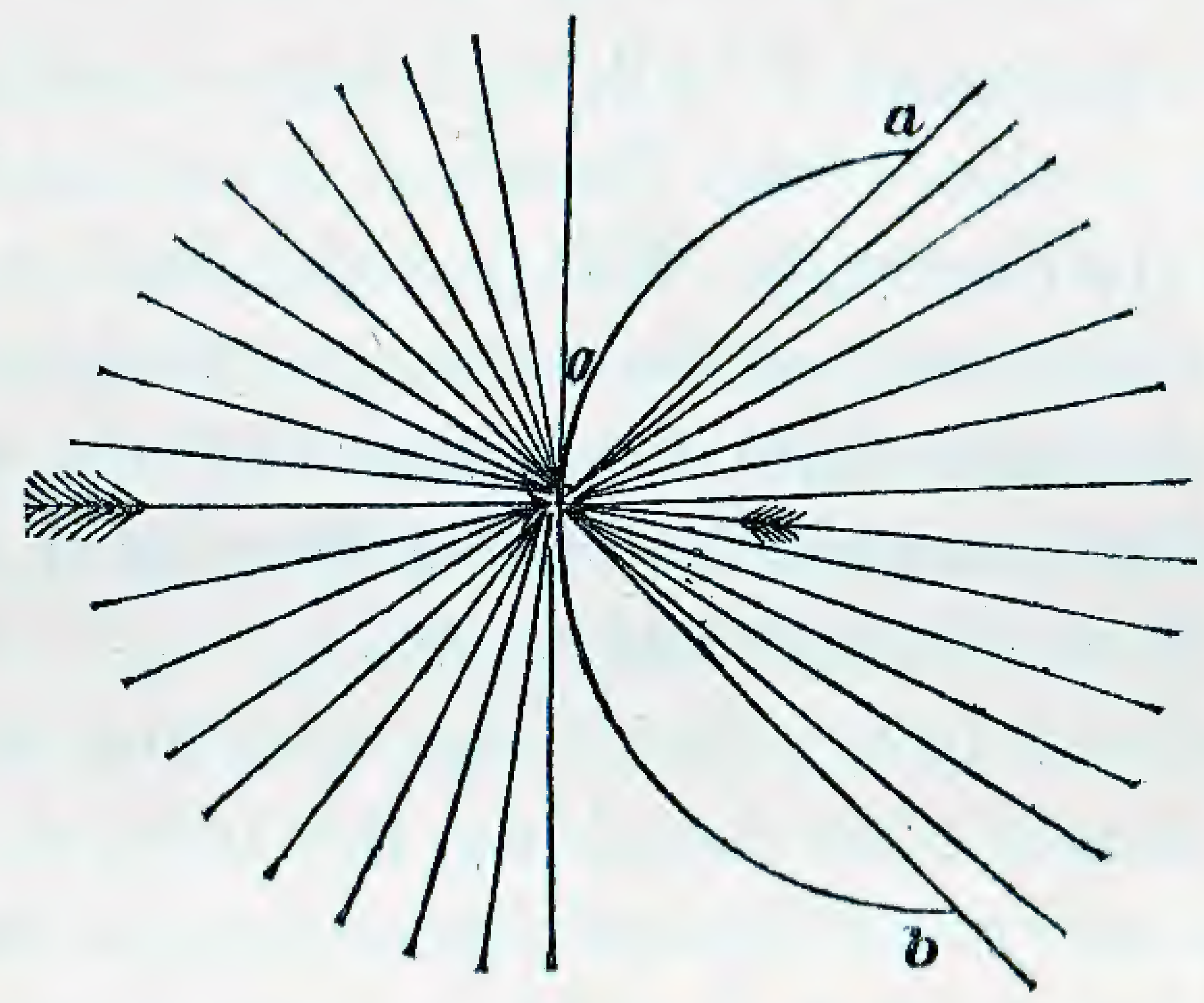
If at this degree of rarefaction the vessel be touched with the moistened finger, or only breathed upon close to the tube fused in above the fly-wheel, the discharge and phosphorescence phenomenon disappear for some time. Moistening the vessel below the wheel does not cause this effect.

I will at this point first explain the third case of all the phenomena of motion, in which the fly-wheel at 0·02 mm. pressure of mercury revolves towards the concave side after breaking the inductive current. Here manifestly *only* the thermal action of the current can be the cause of the rotary motion.

We will now see how a motion towards a concave side can be caused by the equable heating of a semicylindrical aluminum plate. In fig. 45 *a o b* represents the section of such a vane. The molecules approaching from both sides rush back from the equably warmed plate with a greater velocity, and from their reaction against the plate there result two opposite pressures normally directed against the same. For simplicity, we will consider a small element of the surface at *o* on the apex of the vane. At the concave side, only those molecules react on the element of surface which rush away in all directions inside the aperture *a b*. The other molecules will give up the motion received from the element of surface somewhere on the concave side of the plate. A part, so to say, of the moved molecules will be caught on the concave face, and not come into effect.

The resultant of all the reacting forces on the element of surface on the convex side must therefore, as is apparent from the sketch, be greater than on the concave side, and the plate will move with the concave side forwards. Such a fly-wheel, whose temperature is higher than that of its surroundings, thus moves in the same direction as under the action of rays of light, which for the most part, too, are converted into the heat of the metal vanes. The partially *reflected* rays of light unite in a focal line and raise the temperature there. The colder gas streams over the convex side towards the focal line, and carries

Fig. 45.



the vane with it in consequence of the friction, which at this rarefaction is scarcely three times smaller than at the atmospheric pressure. The rays of light reflected and converted into heat act in the same direction.

An irradiated or warmed wheel with concave vanes thus moves towards the *concave* side. If, on the other hand, the glass vessel be warmed, for example by placing it in a warm atmosphere, the motion must take place towards the *convex* side.

After this consideration, I proposed the further question whether, and how, a semicylindrical pair of vanes would move when *insulated* from the point by means of a glass cap. If the above view of the thermal action of the induction-current were right, and if there were no other cause of motion besides this thermal action, the pair of vanes must now remain at rest, since the discharges *only* proceed from the metal point.

Experiment, however, did not verify this conclusion. The pair of vanes rotated with the *convex* side forwards, and that

too at the most extreme rarefaction, when the glass sides were phosphorescing briskly. After breaking the current a rotation took place in the opposite direction.

Since glass, as is well known, conducts the induction-current tolerably well, the possibility was not excluded that electricity discharges through the metal point, the glass cap, and the wings. I therefore constructed a pair of vanes of semicylindrical mica plates, and insulated them by means of a glass cap from the needle-point. This fly-wheel, too, at an extreme rarefaction showed a motion towards the *convex* side and rotated in an inverse direction when the current was broken.

From this experiment I believe I may conclude with certainty that the motion of the fly-wheel is *indirectly* caused by the particles of the electrode. The particles heat the glass sides, and it is the radiant heat of the latter, and the particles of gas rushing back violently into the interior of the vessel, which cause the motion towards the *convex* face, as in an ordinary radiometer with semicylindrical vanes.

If the experiment lasts a long time, the vanes are gradually warmed, and rotate after breaking the current towards the *concave* face, on account of the quicker cooling of the glass sides.

I will here remark that fly-wheels both of aluminum and mica also rotate at a pressure of about 400 mm. towards the *convex* side, most probably in consequence of faint discharges at the points of the vanes, thus acting as ordinary fly-wheels. At other degrees of rarefaction, the wheels remained indifferent or their motion took place towards one side or the other.

The idea naturally suggested itself, that in Crookes' radiometer, too, the motion towards the aluminum face at an extreme rarefaction, first noticed by me, is due to the same cause, viz. to the *heating of the side* by the particles repelled from the kathode.

For this purpose I have constructed a pair of vanes of very thin brass and mica, and insulated it from the point by means of a glass cap. At an extreme rarefaction the wheel rotated several times, first of all towards the metallic face and afterwards rather quickly towards the mica face. The glass cap rattled on the point so loudly that the noise could be heard in the next room, even when the door was closed. The

jumping motions of the wheel took place in a vertical direction, as if the point would throw the former upwards.

That the wheel does not continuously rotate towards the metallic face may be accounted for by the fact that the thin foil very soon acquires the temperature of the sides, since the latter are only warmed by the rays of a thin needle. If the temperature of the sides of the vanes is the same on both faces, no rotation takes place. The metallic face is afterwards, however, more strongly warmed than the mica one, and rotation towards the latter must therefore take place.

After these experiments the supposition appears to me *very probable* that the motion of the vanes towards the aluminum face at the highest rarefaction is a consequence of the *heating* of the glass sides by the kathode rays.

It was also to be expected, from these experiments, that the electrical current at a lower degree of rarefaction, when the glow-light appears, would warm the kathode more strongly than at the highest rarefaction, when phosphorescence is produced. In the first case very probably the detached particles of the electrode strike against the kathode very frequently, and restore part of their motion to it, whereas in the latter case most of the particles strike and warm the glass side.

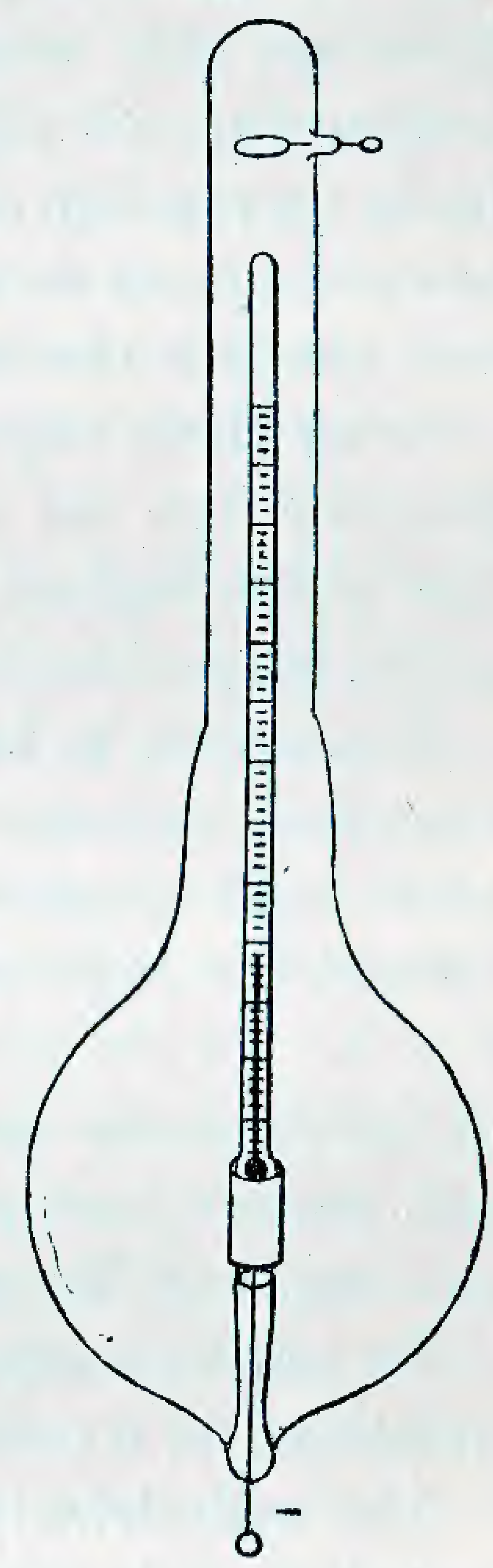
To test this supposition, the temperature of the kathode was measured in a pear-shaped glass vessel at different pressures.

The cylindrical bulb of the thermometer was so closely surrounded with aluminum foil that the discharges could only take place towards the outside (fig. 46, p. 290). The thermometer-bulb was very small, and rested on a small glass tube in the middle of the glass vessel. Experiment showed, as I have predicted, that the temperature of the kathode is greater when immerged in glow-light than when the glass walls surrounding the thermometer-bulb phosphoresce. In the former case the temperature was 47° C., in the latter 41° C., in spite of the smaller thermal conductivity of the rarefied gas. This proves conclusively that the temperature of the kathode decreases if the rarefaction increases.

There are thus two forces principally which cause the motion of the wheel at a high degree of rarefaction :—1, the action of heat on the vanes ; and 2, the action of heat from the surrounding glass side. Each action is opposed to the other ;

the former drives the vanes towards the *mica* or *concave* face in consequence of the reaction of the molecules of gas, and the latter, as in an ordinary radiometer, towards the *metallic* or *convex* face.

Fig. 46.



If the induction-current passes through the radiometer at a pressure of 0·02 mm., the reaction of the particles of gas on the vanes is enfeebled by the thermal action at the glass sides and the motion of the fly-wheel is less rapid; it is much more rapid, on the other hand, when the current is broken, because the whole thermal action comes into force on the vanes.

At a certain degree of rarefaction both actions are in equilibrium, and the motion first commences after breaking the current.

At a still higher rarefaction than 0·02 mm., when the glass sides are phosphorescing vividly, the thermal action of the glass sides preponderates and the rotation of the wheel therefore takes place towards the *convex*, *i. e.* the *metallic* face of the vanes.

The cause of the rotation of the wheel towards the convex face between the pressures 140 and 620 mm. is to be looked for in the fact that the positive or ultimately the negative discharge only takes place at the *corners* of the vanes into the *gaseous space*. The particles of gas charged with statical positive or negative electricity are repelled, and their reaction drives the vanes in the opposite direction and thus towards the *convex* face. It is obvious that a semicylindrical vane acts like a system of four points directed towards the same side. In the second vane the corners are oppositely directed, and act thus in the same direction as the first.

At full atmospheric pressure the discharge at the corners of the vanes does not take place into the gaseous space but on to the glass side, because small sparks strike across. These discharges appear to me to be the cause of the motion of the wheel which takes place towards the concave side of the vanes.

On bringing the palm of the hand near to the glass vessel

this discharge is prevented, the electricity again discharges itself into the gaseous space, and the rotation takes place at this pressure also towards the convex face.

Whether the statical charges of the glass sides do not influence the motion of the wheel in one direction or the other I have not been able up to now to ascertain.

I purpose shortly carrying out an exact investigation of the statical charges of the glass vessels, and will only mention here that at an extreme rarefaction *both* ends of the wire are *negatively* and the whole glass vessel positively electrical, and that the neutral point with zero tension lies outside the glass vessel.

Electrical Radiometer with Phosphorescent Vanes.

The fly-wheel of the electrical radiometer represented in fig. 47 (p. 292) consists of two obliquely placed mica plates which are covered on one side with a phosphorescent substance and are suspended free to move by means of a glass cap on a needle-point. An arrangement of copper wire prevents the fly-wheel from falling off when the apparatus is inverted.

Ordinary chalk and some sulphur compounds were used as phosphorescent substances, and of the latter the green phosphorescent calcium sulphide is especially distinguished by the high intensity of its light.

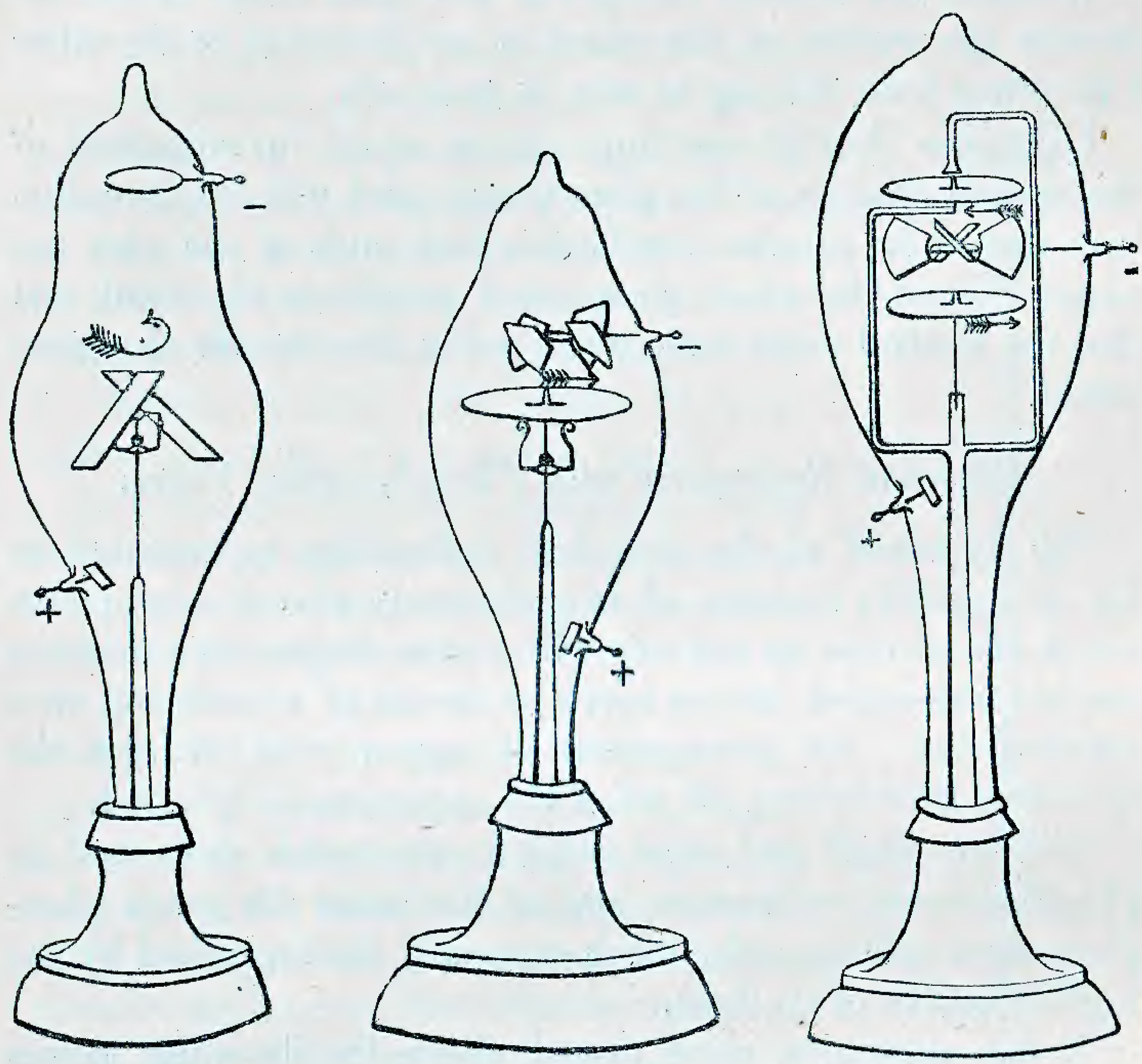
A flat aluminum plate placed above the fly-wheel serves as the negative electrode, and is covered with mica on the face away from the wheel. On the passage of the electrical current a conical bundle of rays proceeds downwards from the negative electrode, causes a vivid phosphorescence of the vanes and sets them in rotary motion, which takes place in the direction of the emission of the electrode particles from the kathode.

Electrical Radiometer with Phosphorescent Disc.

A horizontal mica disc turning on a needle-point is divided into sectors and painted with different phosphorescent substances. An aluminum plate cut through in four quadrants serves as the negative electrode, fig. 48. The individual quadrants are placed obliquely towards the mica plate below and take the form of a screw ; the side of the electrode facing

upwards is covered with mica in order that the discharges may only take place downwards.

Fig. 47. Fig. 48. Fig. 49.



At a pressure which is greater than 0·02 mm. the mica disc turns in a direction corresponding to an emission of electrode particles perpendicular to the surface of the kathode, and which we will call a normal rotation. At a greater rarefaction a rotation of the disc takes place in an opposite, abnormal direction, and is to be explained by the fact that the discharges take place principally at the edges of the electrode. In this radiometer an exceedingly rapid rotation of the disc was also noticed when the wires were put to earth, and the radiometer was standing close to the Ruhmkorff apparatus without being in connexion with the poles. The rotation took place sometimes in the one, sometimes in the other direction.

This radiometer shows another remarkable motion. If, namely, the lower electrode, a small plate of aluminum, be used as the kathode, the plate rotates at the greatest rarefaction

with a very great velocity in the *normal* direction, thus opposite to the direction of rotation on inversion of the current.

The rays proceeding from the small electrode are distributed almost equally in all directions, and it is therefore inexplicable how *any* motion *at all* of the disc could take place.

The drawing fig. 49 represents an electrical radiometer with two rotating discs; the screw-shaped kathode emits electrode particles against both discs, and causes, at a small rarefaction (0·06 mm.), a rotation in a normal direction. At a greater rarefaction an inversion of the direction of rotation of both discs takes place.

If the lower small electrode be connected to the negative pole of the Ruhmkorff coil, or if the current be inverted, an exceedingly rapid rotation of the lower disc again takes place in a *normal* direction. The rotation of the upper disc is much slower and in the same direction as the lower one, most probably in consequence of the internal friction of the gas, which, as is well known, is still very great even at the highest rarefaction, and in air 50,000 times rarefied scarcely three times smaller than in air of ordinary density.

Phosphorescent Lamp.

A mica lamina covered on one side with green phosphorescent calcium sulphide is fastened obliquely to the vertical in a pear-shaped glass vessel in such a manner that it will be struck by the kathode rays which are emitted from a suitably placed cup-shaped aluminum electrode. Near to the kathode a small plate of aluminum is placed on the side to serve as an anode. Fig. 51 (p. 294) represents the lamp in a somewhat different form. It consists of a simple glass tube having in the centre an obliquely placed elliptical plate of mica covered with sulphide of calcium. Below the mica plate is a disc of aluminum of the same diameter as the section of the tube which serves as the kathode. Above the mica plate is the much smaller anode.

The light of the phosphorescent lamp is sufficiently brilliant to light a room, and it is possible to read even at some distance from it.

The light intermits as often in a second as the primary current is broken; on account of the longer duration of the

impression of light, however, the lamp appears continuously luminous, and the intermittent character of the light is only recognized by observing bodies in motion, which then appear multifold.

Some lecture experiments may be introduced here which can be performed by means of the light of the intermittent lamp.

Fig. 50.

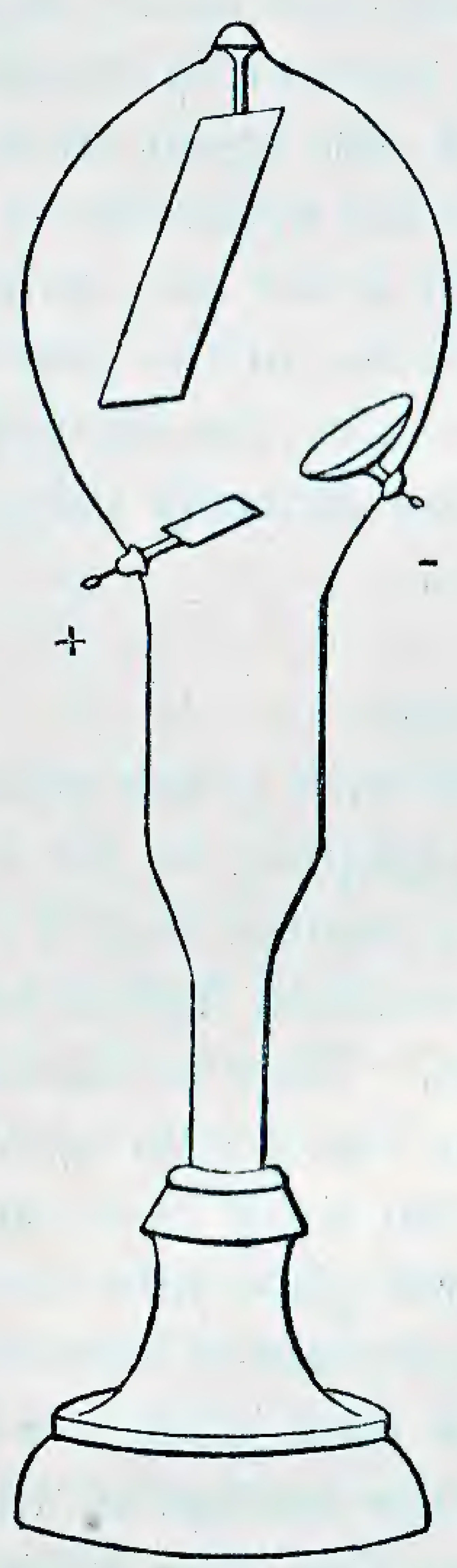
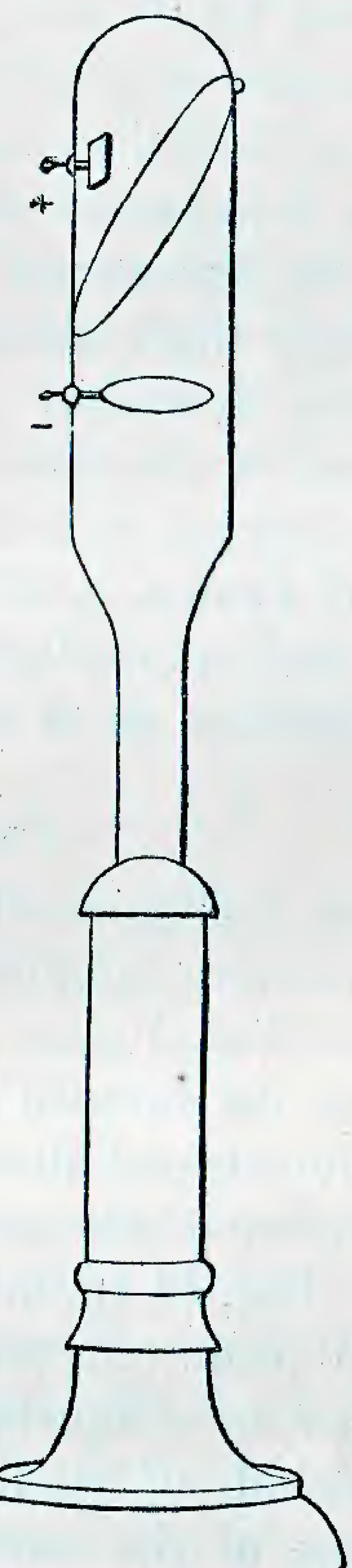


Fig. 51.



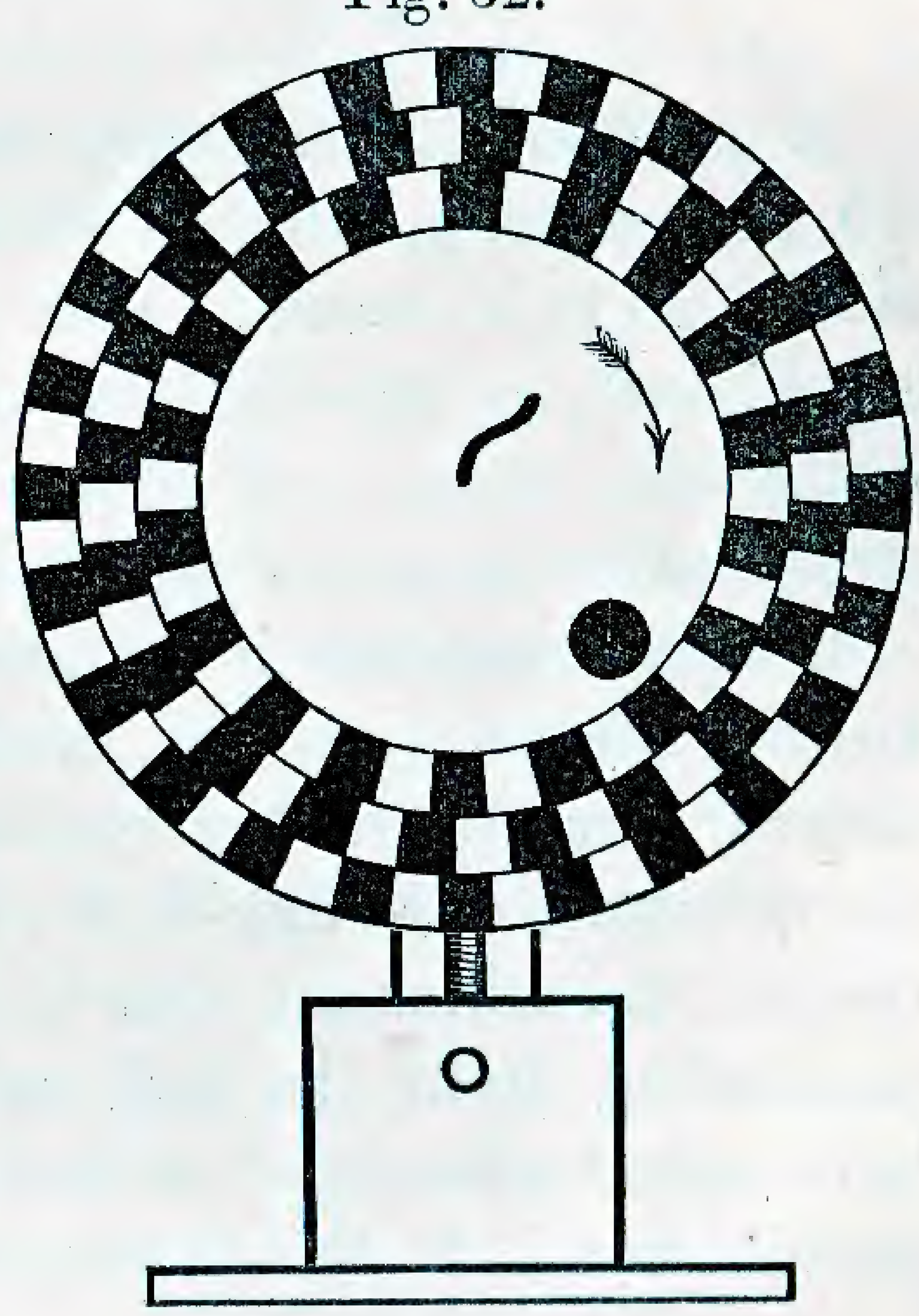
(a) *Experiment with a Mirror.*—If the image of the lamp is looked at in a large mirror which is swung to and fro by means of the hand about a horizontal axis, a whitish elliptical broad streak of light is seen with individual very bright spots of light, the number of which is smaller the quicker the mirror is moved.

(b) *Free fall.*—A large screen of tissue-paper is placed in front of the lamp and separate drops of mercury are allowed to fall in front of it in rapid succession. The paths traversed by the drops appear on the screen in equal times. If an apparently continuous stream of water be illuminated by the lamp, it appears to be resolved into single drops of water.

(c) *Experiment with a Sphere.*—A glass sphere of about 4 cm. diameter is swung on a string in a circle in front of the screen, which is illuminated behind. It appears fourfold if, during the time of its describing a circle, the current is four times broken. The four images of the sphere would always appear at the same place if the velocity of rotation were constant. If the rotation be accelerated, the images are formed at other points of the circle, and the four spheres are seen to advance on account of the longer duration of the impression of light. With a retarded rotation the spheres rotate in the opposite direction. If the sphere be allowed to oscillate about a point as a pendulum, the velocity at different points of the circular path is seen.

(d) *Experiment with the Stroboscopic Disc.*—A disc of cardboard, painted with three concentric circles of black squares, as represented in fig. 52, shows a magnificent optical phenomenon when set in rotation by clockwork andi lluminated by means of the intermittent lamp. Whilst the disc is rotated constantly in one direction, one circle appears to turn in the direction of the hands of a watch, a second in an opposite direction, whereas the third remains apparently at rest; but immediately on altering the velocity of the screen itself, turns in the one or other direction. A curved line drawn radially on the screen, as well as a round black spot, appear to be multiplied, which is to be explained analogously to the several images of the rotating sphere. If the rotating disc

Fig. 52.



be retarded by means of the finger, a velocity can easily be obtained at which the first, second, or third circle of black squares remains at rest. This manifestly is always the case when a black square comes into the position of the next or of the second or third during the time that the lamp remains dark, because in this case the eye does not observe the motion of the black squares.

(e) *Experiments with Vibrating Wires.*

1. *Objective representation of the true form of a vibrating wire.*—If a wire is vibrating in several segments, separated by nodes, the particles in vibration on opposite sides of a node are, as is well known, in opposite phases of motion, so that the particles of the wire in the one segment move upwards from the position of equilibrium if in the neighbouring segment the motion is downwards. The particles attain their greatest elongation from the position of equilibrium after a quarter of a vibration and the wire forms a wave-line, symmetrical about the position of equilibrium, consisting alternately of elevations and depressions. This curved form of the vibrating wire can be represented objectively by means of the phosphorescent lamp.

Fig. 53.

To produce the vibratory motion I use a white silk thread 3·5 metres long, and an electrical tuning-fork giving 114 vibrations in a second. One end of the thread, as in Melde's experiment, is attached to one prong of the tuning-fork, whilst the other end is passed over a pulley and suitably stretched by means of weights.

If the tuning-fork is vibrating there are formed, as is well-known, *stationary* waves, consisting of several loops whose number varies with the tension of the thread, and is greater the quicker the tuning-fork vibrates, in comparison with the thread, and which are due to the interference of the waves proceeding from the fork and reflected at the pulley, which have equal phases of vibration, but opposite directions of propagation. If the tuning-fork makes n times as many

vibrations in a second as the thread would make with its tension and length, the latter divides into n segments, of which each two adjacent ones move in an opposite direction, but vibrate just as quickly as the tuning-fork. The thread which, as a whole, cannot follow the vibrations of the tuning-fork, divides into several subsegments, of such a length that each one vibrates just as quickly as the tuning-fork at the tension existing in the thread. I demonstrate the latter fact in lectures by bringing a strip of stout paper, or a small paper screen, close to a loop. The rhythmical impulses of the vibrating thread give rise to a tone, audible at great distances, of the *same* pitch as that of the tuning-fork.

If now the lamp described became luminous every time that the particles of the thread reached the position represented in fig. 53 of their greatest elongation from the position of equilibrium, an observer must see the wave-like form of the thread at the same place every time. If, moreover, the flashes of light followed one another so quickly that the interval of time between two flashes was equal to the duration of the luminous impression, an observer would see the wave-like form of the thread under an apparently *constant* illumination and always in the same place.

The condition therefore that the experiment shall succeed, is obviously that the vibrations of the tuning-fork and those of the Neef's hammer shall be *isochronous.*

The wave-like form of the thread must, however, also be apparent if the flashes take place after every second, third, or nth vibration of the particles of the thread or of the tuning-fork.

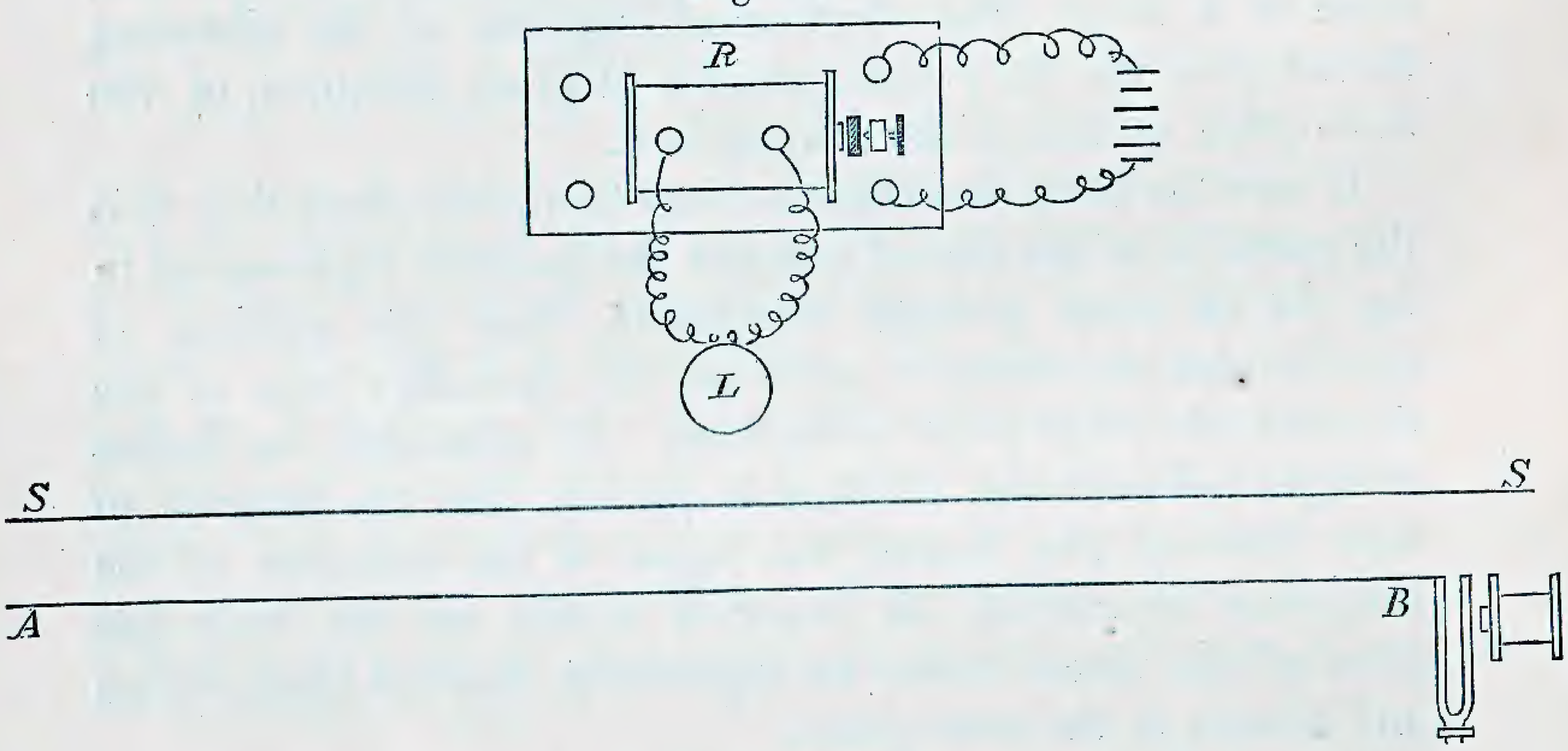
Thus, for example, by using a tuning-fork with 114 vibrations, the wave-line would also be seen if the Neef's hammer were making 19 or 38 vibrations per second. The flashes of light would occur in the first case after every sixth, and in the second after every third, vibration of the tuning-fork.

If the number of vibrations of the Neef's hammer only differs slightly from that of the tuning-fork, which can be brought about at any time by regulating the screw, a slow to and fro vibration of the wave-like form of the thread is observed about the position of equilibrium, *in which each*

vibration of the thread is accompanied by a modulation of the tone. The particles on both sides of the nodes move in this case always in an opposite direction.

The arrangement of the experiment is diagrammatically represented in fig. 54. AB is the vibrating thread with the electrical tuning-fork; L the phosphorescent lamp which is set in operation by the Ruhmkorff apparatus R, and SS is a screen of tissue-paper.

Fig. 54.



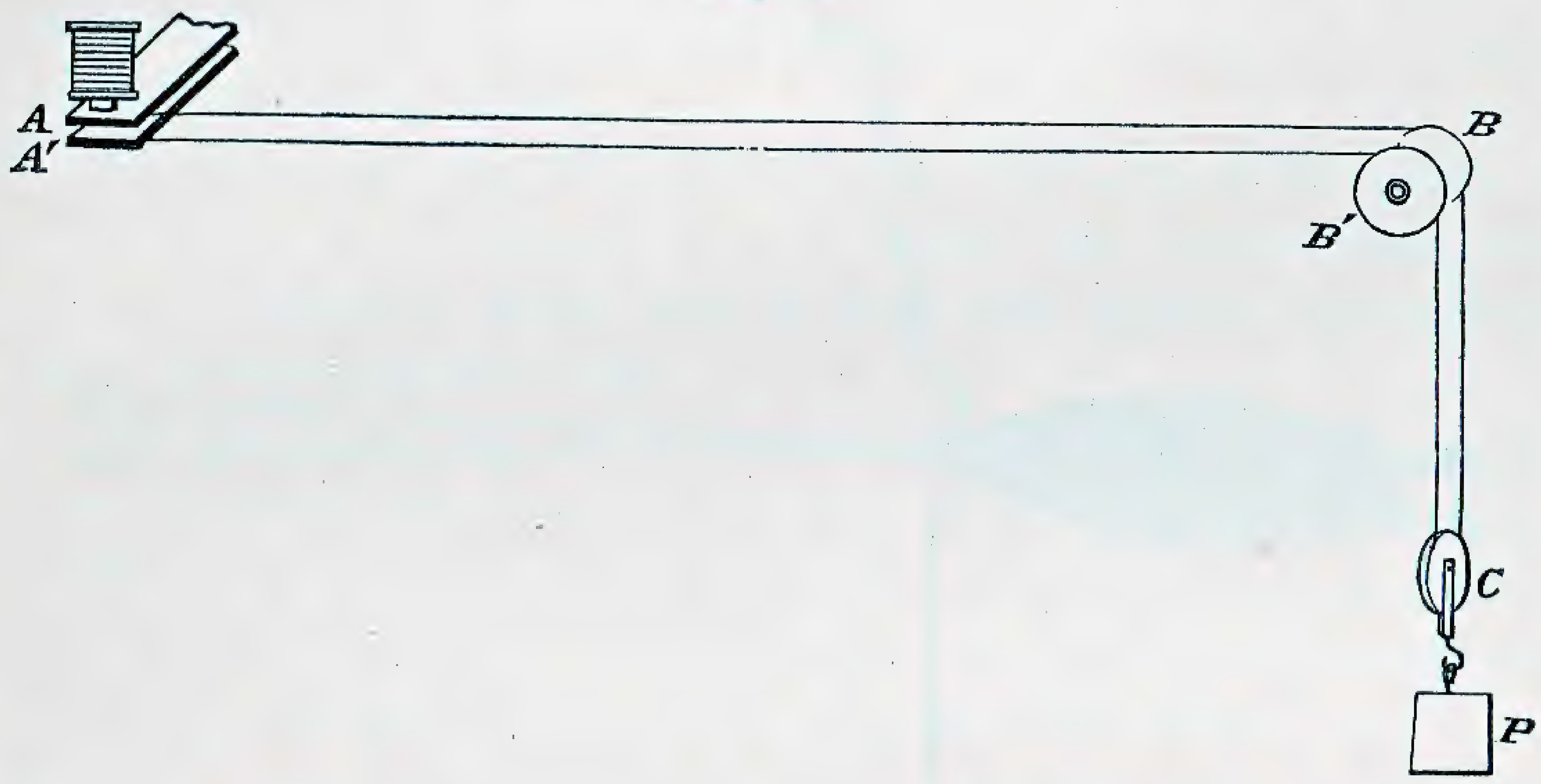
2. *An interference experiment with two vibrating wires.*— Two wave-motions which are propagated in a medium in the same direction destroy each other, as is well known, if the difference in the length of path of both waves is an unequal number of half wave-lengths.

This result of the undulatory theory, which was first of all deduced to explain the acoustical phenomenon that in certain cases two tones can destroy one another, can be proved for *longitudinal* vibrations by means of König's interference-tubes. An analogous experiment in acoustics for *transverse* vibrations has up to the present been wanting, and the chief proof of the undulatory theory of light, which consisted in the fact that if light be added to light under certain conditions darkness ensues, had, critically considered, no perfect analogy in *experimental* acoustics.

To cause interference of transverse vibrations two silk cords, AB and A′B′, 3·5 m. long, equally stretched by means of a movable pulley C and the weight P, as represented in

fig. 55, are set in vibration by the two prongs of an electrical tuning-fork.

Fig. 55.



Both silk cords divide into an equal number of ventral segments corresponding to the tension and the length of the cord chosen, as shown in fig. 56. On illuminating both silk cords by means of the phosphorescent lamp

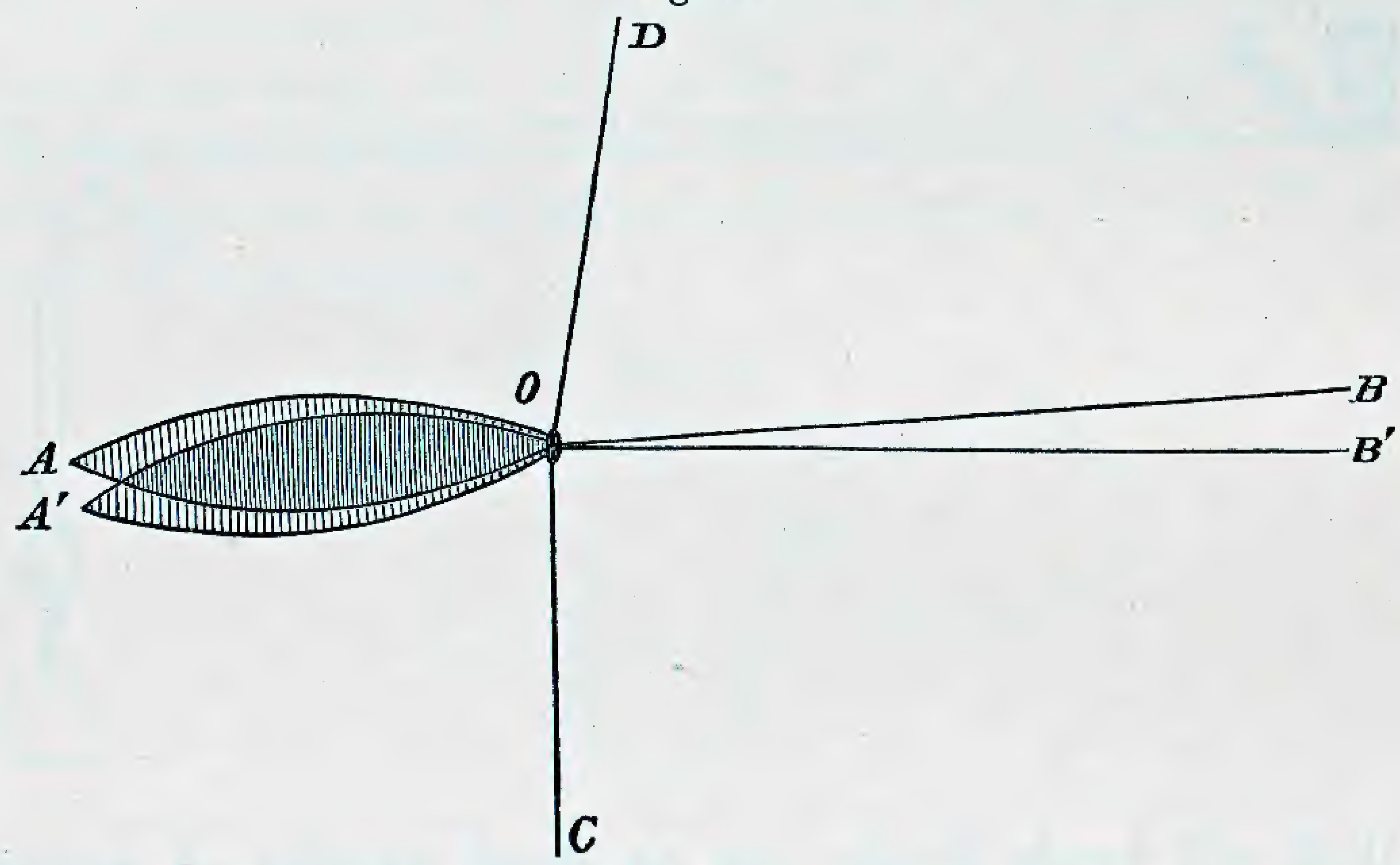
Fig. 56.

Fig. 57.

they appear as two wave-vibrations, which differ from one another by half a wave-length, so that an elevation in the one silk cord is opposite to a depression in the second. To cause both wave-vibrations to interfere at any point, it is only necessary to tie a silk thread round two opposite ventral segments, and to draw the loop carefully together. The wave-vibrations proceeding from the two prongs destroy each other in the loop O, fig. 58, and the threads OB and OB′ on

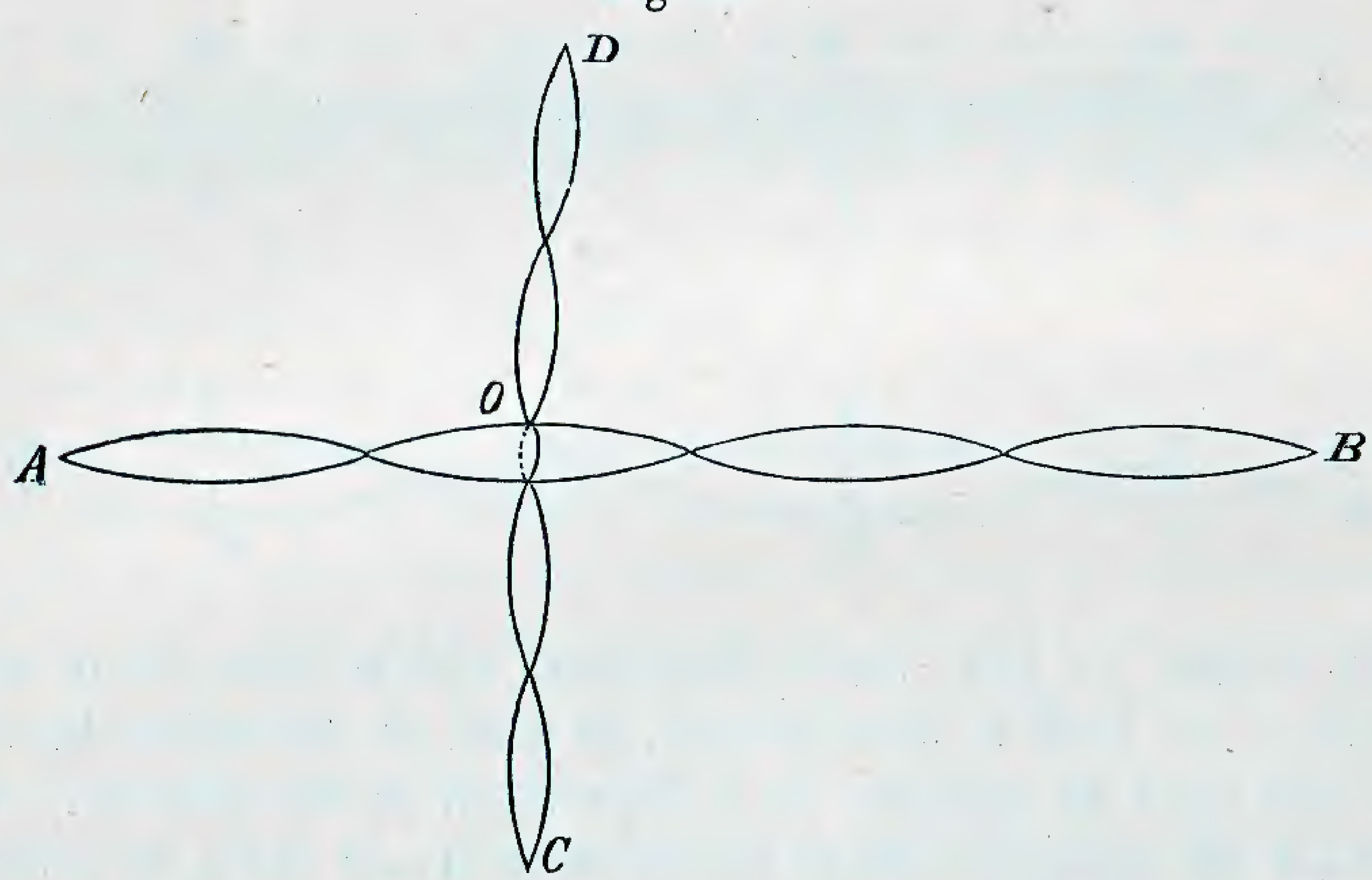
the other side of the loop, as well as the two halves of the looped thread OC and OD, remain at rest.

Fig. 58.



On the other hand, the vibratory motion is propagated unaltered through the loop if the latter only contains *one* silk thread, in which case the looped thread vibrates also and divides into several ventral segments separated by nodes (fig. 59).

Fig. 59.



The experiment on interference with two vibrating threads, represented in fig. 58, forms a complete analogy to the interference of two rays of light which mutually destroy one another, as in Fresnel's experiment with the mirror, if the difference in the length of path is equal to half a wave-length,

because in this case, as with light, transversal and not longitudinal vibrations are caused to interfere.

Vibrating tuning-forks and plates also, when illuminated by means of the phosphorescent lamp, show similar phenomena to the vibrating wires.

For the lamp, fig. 50, a current giving a 3 to 4 cm. spark is sufficient. A stronger current heats the mica plate, the phosphorescence ceases, and a dark spot appears surrounded by a phosphorescent ring.

For the lamp, fig. 51, a current of 5 to 6 cm. spark-length can be used, because in this case the rays are not concentrated. A stronger current is necessary to heat the mica plate, and therefore with this lamp a luminosity of almost twice the intensity of the first lamp is obtainable.

Action of Approached Conductors on the Electrical Discharges.

If the glass vessel, fig. 50, be touched above the mica plate with the hand or any conductor, or be only breathed upon, the discharges in the lamp are often diminished even to an entire extinction of the phosphorescent light if the current is not too strong. By breathing on the vessel, the discharges are prevented as long as it remains moist. But even the approach of a conductor, too, may considerably enfeeble the discharges.

This phenomenon is noticed with the first lamp in yet another way. If the flat aluminum plate is first used as the kathode, in which case the ascending rays strike the whole surface of the mica plate, and the current is afterwards inverted, the mica plate shines at first only faintly but after 3 to 4 seconds suddenly brightens.

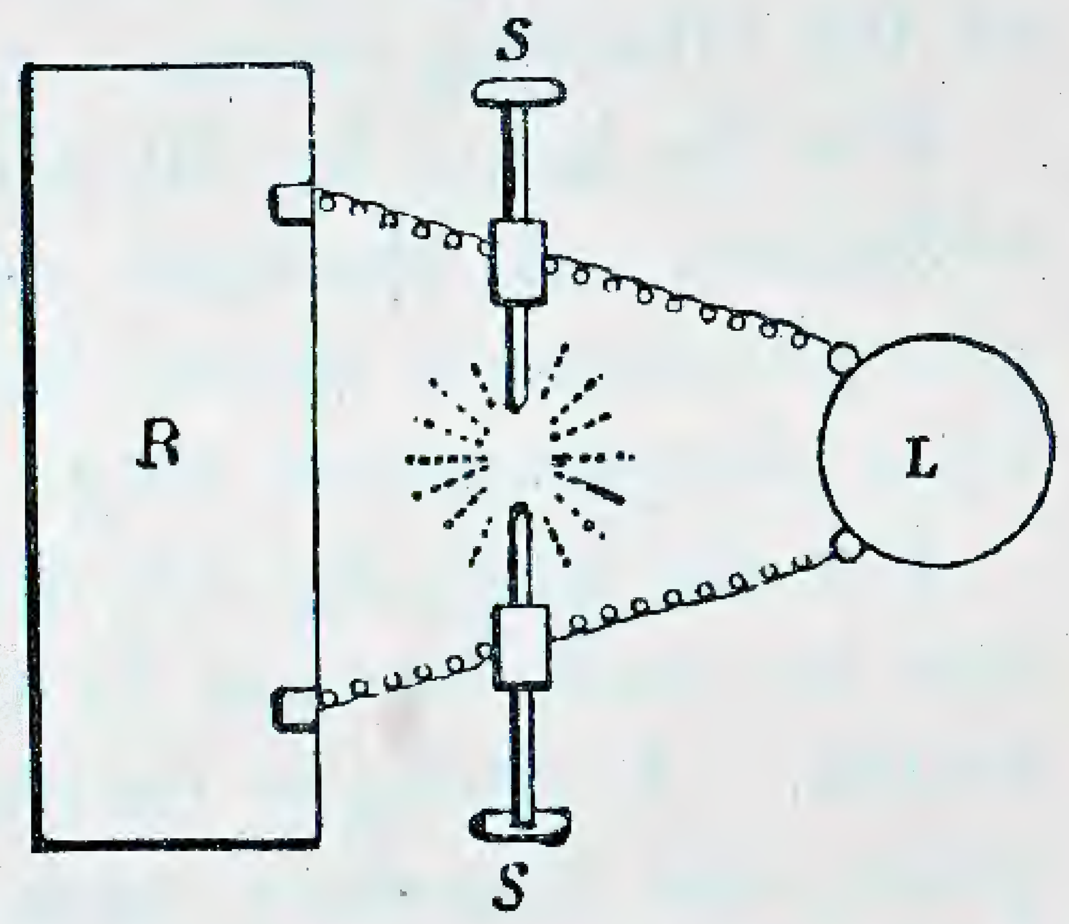
If in the second lamp, fig. 51, the mica plate be irradiated first from above and then from below, the spot of light is not only at the commencement very faint, but is *diverted* towards the upper edge of the plate, and suddenly springs after the course of some seconds towards the middle of the plate and becomes brighter.

These and other phenomena of the enfeeblement and cessation of the electrical discharge I endeavoured to explain by supposing *that the statical electricity of the mica plate repels the approaching electricity in the wires.*

If this view were correct, the current electricity must discharge itself at another part of the conductor, where the resistance is less than that in the evacuated space.

It is therefore only necessary to introduce two discharging points between the two conducting wires, and a striking distance can always be found such that a discharge will take place between the points as soon as the glass vessel is breathed upon or is touched with the hand. The arrangement of the apparatus is represented in the accompanying sketch; R is the Ruhmkorff coil, S the discharging points, and L the lamp.

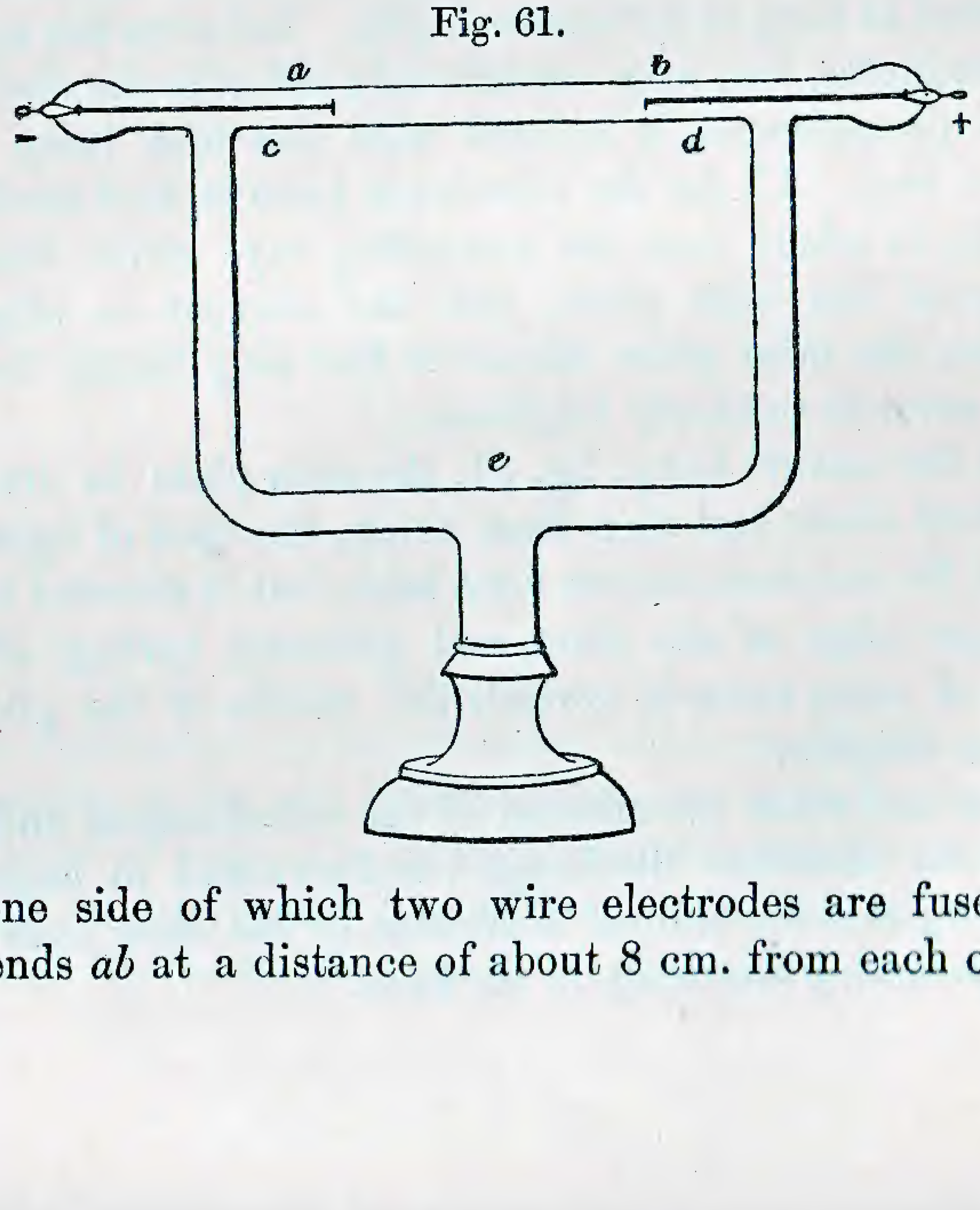
Fig. 60.



Apparatus for Demonstrating that Electrical Discharges in a Vacuum are prevented by the Statical Electricity of the Sides.

In order to demonstrate this phenomenon easily, I have constructed an apparatus having the shape of a rectangle,

Fig. 61.



into one side of which two wire electrodes are fused with their ends *ab* at a distance of about 8 cm. from each other.

At a rarefaction of about 0·06 mm. pressure the electrical discharges take place along the short distance *a b* and the much longer one *c e d*. But if two fingers be placed about the horizontal limb, close to the ends of the electrode, the electrical discharge ceases between the points and becomes stronger along the layer of air *c e d*, which is almost five times as long.

On touching the vertical limbs at *c* and *d*, the discharge can be repelled into the horizontal limb. It is to be expected that by a corresponding choice of the dimensions of the apparatus and of the pressure, the discharge will *only* take place along the shorter distance *a b*, and on touching the glass side with the hand or with a good conductor, tinfoil for example, it will be driven into the lateral tube, which can also be bent a number of times.

In the London Exhibition of 1868 Prof. Hittorf exhibited a tube which showed a similar case of electrical discharge, and which in my view finds its explanation in the action of statical electricity on the electrodes.

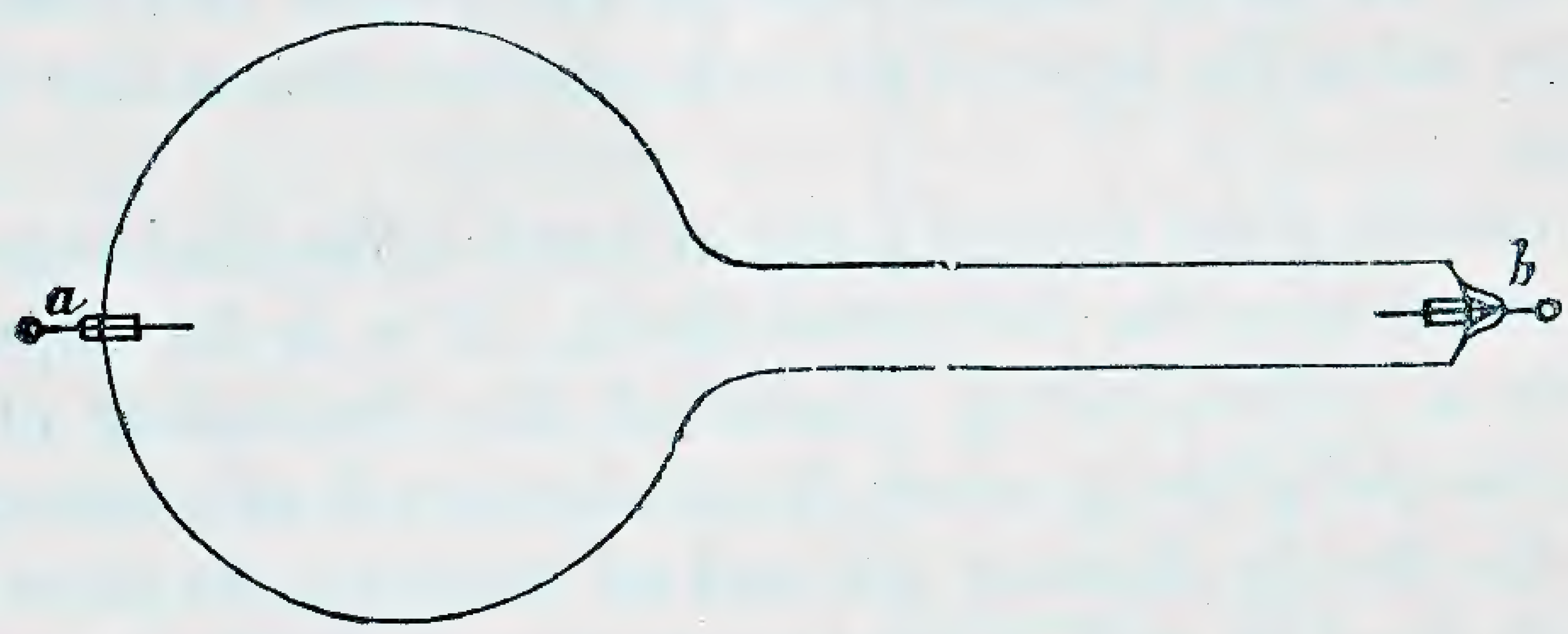
It was a sort of spectrum-tube with a capillary centre piece. The two wide end pieces communicated with each other by means of a side tube twice bent, and were provided with wire electrodes which projected into the capillary part of the tube. The ends of the electrodes were only a few millimetres apart from each other. At a very great rarefaction the electrical discharges did not take place through the shorter distance in the capillary part of the tube, but through the much longer lateral tube.

After what has been said, there can now be no difficulty in explaining this phenomenon. The density of the statical electricity on the sides of the tube will be greater the smaller the section of the tube. Whilst, therefore, the density of the electricity in the capillary centre piece is sufficient to prevent the discharges there, the electrical discharges take place in the *wide* parts of the tube on account of the small density of the electricity of the sides.

That electrical discharges at the highest rarefaction are influenced by the *proximity* of glass sides charged with statical electricity can be demonstrated in an apparatus (fig. 62, p. 304) which we will call an "electrical valve." **A** wire-

shaped electrode a is fused into a bulb and a second perfectly similar one (b) into a thin tube joined on. At a sufficient rarefaction no current passes when b is used as the kathode,

Fig. 62.



whereas after inverting the current, when a becomes the kathode, a vivid discharge takes place.

It is better to use an influence-machine for these experiments than an inductorium.

After having established these facts it is no longer difficult to explain an experiment which has already been described on p. 255; that is, the phenomenon observed in the bulb-tube represented in fig. 5, *that at high degrees of rarefaction the electrical discharge takes place at that point on the kathode which is nearest to the anode,* which, as Mr. Crookes has experimentally determined, is not the case at moderate rarefactions, when the kathode rays are propagated in a straight direction quite independently of the anode. The negative charges of the glass sides will be weaker near to the anode than at all other parts of the glass tube, on account of which the discharge will also take place most easily at that point on the kathode which is nearest to the anode. Thus in the bulb-tube (fig. 5) the kathode discharges itself even in the narrow tube d if a be used as the positive electrode, whilst the discharge in the bulbs B, C, and D is prevented by the action of the electrified sides.

From my point of view, too, the very interesting phenomenon which I have often observed can be quite easily explained by means of statical electricity, namely that a tube flooded with blue glow-light touched at one point with the finger shows a very bright phosphorescent spot on the opposite side, *as if the point touched were a kathode.* The point in consequence of being

touched becomes *strongly negatively electrical* on the inner side, and the particles of the electrode flying past, parallel to the side, are caused to diverge from their straight paths by the statical electricity of the side, and are diverted towards the opposite side, which phosphoresces on being struck by the particles.

The cessation of electrical discharges in strongly evacuated tubes is often put forward as a proof of the unitary view of the nature of electricity. If, as is considered, the electric current consists in the progressive transport of an imponderable matter, the æther, the discharges must continue even in the best vacuum, for æther is still present in it. In opposition to this it may be remarked that electrical discharges take place the more easily at the same degree of rarefaction the further the sides are from the kathode ; and after what has been said we are justified in expecting *that electrical discharges would take place even in the best vacuum if the inevitable charges of the adjacent glass sides were not present.*

How are the Statical Charges of the Glass Sides formed?

The statical charges in the neighbourhood of the negative electrode can be formed either by induction due to the kathode, or in consequence of the direct transmission of statical electricity by the particles thrown off from the kathode which are charged with statical negative electricity.

By such an induction the phenomenon is to be explained that bodies which are close to a kathode are no longer repelled at the highest rarefaction by the particles of the electrode which are thrown off, but *are attracted* by the kathode. I often noticed this attraction, even at a small rarefaction, when a mica plate was placed opposite a platinum electrode in order to coat it with a platinum mirror.

In another apparatus an aluminum plate, which served at the same time as the anode, was placed at a distance of about 2 to 3 mm. below the kathode, and the attraction was so strong that the plate was bent round and was united with the kathode.

The statical electricity is, however, also *directly* transmitted to the walls, since, according to the view advanced and verified in many cases by me as to the nature of radiant electrode

matter, very small solid particles, charged with negative electricity, are torn off and thrown from the kathode and give up for the most part their negative electricity to the surrounding sides. The negative electricity of the inner glass sides attracts the positive electricity of the outer sides, whilst the negative electricity of the latter is given up to the external air.

The evacuated glass vessel thus forms a sort of Leyden jar with an internal negative and an external positive charge, which often, especially at the highest rarefaction, are so strong that the thin glass sides are perforated. As I have already mentioned in another place, the external charge of a glass vessel is positive at the highest rarefaction, whereas the kathode, as well as the anode wire, are negatively electrical. The glass apparatus was tested as to its electrical charges by means of an insulated copper wire, which was first of all made to touch at different points of the glass side, and then brought into connexion with the conducting wire of a very delicate quadrant electrometer. It was shown thereby that the density of the statical electricity was at its maximum opposite the points of discharge of the kathode.

I may mention further in connexion with this that strongly evacuated glass tubes, and vessels like a Leyden jar, require a longer time in order to become *charged* with statical electricity, and that they only discharge in the interior after reaching a definite potential. This gradual charge and sudden discharge can be very beautifully observed with the phosphorescent lamp (fig. 51, p. 295), if it be connected with the conductors of a Töppler's machine. On turning the machine slowly the lamp continues dark for some time, and becomes suddenly very bright as soon as the discharge takes place in the interior. The flashes of light take place more quickly the faster the machine is turned.

Electrical Phenomena in the Celestial Vacuum.

How far the so-called vacuum, which we can obtain with the best means at our disposal, is removed from an absolutely empty space has been shown by the experiments on internal friction, which Kundt and I have carried out in extremely

rarefied gases*. In air at a pressure of 0·03 mm. of mercury the internal friction, and thus also the conduction for heat proportional to it, is scarcely three times smaller than in air of ordinary density. In air rarefied more than 25,000 times, very considerable quantities of motion can be transmitted from place to place by means of internal friction of the mass of air; for example, a horizontally rotating mica plate sets in motion a second one parallel to it even at great distances. We conclude from this that the mass of gas in an artificial vacuum must be still relatively very large, even at a million-fold rarefaction; according to the calculation of the kinetic theory of gases, a cubic centimetre would still contain about 21×10^{12} molecules of air, which move to and fro between a number of inconceivably small atoms of æther.

We are quite as little justified according to the present state of our knowledge in assuming cosmical space to be void any more than the artificial vacuum. Light and heat radiation furnish, as is well known, a certain proof that the interstellar space is filled with a very attenuated matter which the older philosophers called æther †. Further, by exact measurements and calculations of the astronomers, a constant decrease of the long axis of the path of Encke's comet has been proved, and this decrease in the path of the comet has been ascribed to the retarding action of attenuated matter. It is, however, still an open question whether the retarding medium is identical with the æther or is peculiar to each solar system, and, like the atmosphere about Herschel's nebulæ, surrounds it to a certain distance; so much is, however, certain, that the vacuum of the universe, too, is not absolutely void. If, now, a space filled with æther conducts electricity, it is easily explained how electrical disturbances of equilibrium on one heavenly body must cause the same on all neighbouring ones. Thus, along with gravitation, light, and heat radiation, electricity will also belong to those forces of nature which connect distant heavenly bodies with one another.

It will scarcely be doubted by any one that the northern

* Poggendorff's *Annalen*, clv.; *Sitzungsberichte der k. Akademie der Wissenschaft*, lxxviii.

† In Sanskrit *âschtra* = air circle and the root *as*, *asch* denotes to shine.

and southern lights, which appear almost uninterruptedly in the higher* regions of our atmosphere in the neighbourhood of the poles, attaining sometimes an intensity of light equal to that of the first quarter of the moon, and are even visible in sunshine by their vibrations of light, are ascending electrical discharges. Opinions, however, differ as to the cause of this luminous phenomenon.

De la Rive considers this luminous process as a recombination of the positive electricity of the air with the negative electricity of the earth, which have been separated directly or indirectly by the heat of the sun in the equatorial regions. Why, however, the electrical charges do not combine earlier and only in the polar regions is not apparent, more especially as air is a bad conductor of electricity. If, however, the vacuum of the universe conducts electricity, the supposition lies very close that the polar light is of *cosmical* origin †, and is especially caused by electrical disturbances on the solar surface. Sun and earth form as it were two mighty electrodes in the universe, between which electrical discharges take place through the vacuum. The dependence of the intensity of the phenomenon on the size of the sun-spots also points to a cosmical origin, as was lately observed in the Kew Observatory from April 15–21, when very vivid auroræ boreales appeared in America. The maximum intensity of the aurora was attained on April 17, when the sun's disc showed an extraordinarily large sun-spot.

It is not improbable that such a luminous process takes place on other planets, and certainly Venus often shows a phosphorescent light on the side not illuminated by the sun. Sheet lightning, too, is undoubtedly an electrical discharge in a rarefied atmosphere, which often continues in calm air between the clouds for hours, and so also, most probably, is that luminosity of large clouds without flickering observed by Rozier and Beccaria, as well as the luminosity of dry mist, as in the years 1783 and 1831 ‡. The observation, too, has

* Newton finds by observations of 28 auroræ boreales that the height of these phenomena varies between 33 and 281 English miles above the surface of the earth.—Nature, xxii., p. 291, 1880.

† Edlund, Wiedemann's *Annalen*, 1882, p. 514.

‡ Humboldt's *Kosmos*, 1874, vol. i. p. 127.

often been made that at the time of the aurora borealis dark parts of the heavens shine brightly owing to falling stars. This and still another circumstance, viz., that, after the disappearance of many shooting stars and meteorites, phosphorescent nebular formations remain visible for a long time, render the supposition probable that the luminous phenomena of meteors and meteorites are caused, not only by the incandescence of the outside layer of the moving body, but also by the surrounding gas-masses becoming electrical. Admiral Krusenstein, in his voyage round the world, saw for an hour together the tail of a meteorite which had long disappeared. A similar spectacle was presented by the meteorite of 1873, which commenced to shine 22 miles above the surface of the earth south of Raab, moved over Lower Austria, Moravia, and Bohemia, and became extinguished near Zittau, at a height of 4·5 miles. The intensely white zigzag tail of this meteor was visible for half an hour afterwards. The long duration of the luminosity is not explicable on the assumption that the tail consists of glowing gases, especially if we consider that the loss of heat of bodies in a vacuum by radiation is relatively large, even with a small difference of temperature in the surrounding medium, and must be much greater in cosmical space, the temperature of which, according to Pouillet's actinometric measurements, is said to be $-142°$ C. Even large pieces of carbon, as I have noticed, sink almost momentarily from a white to a red heat in very rarefied air. On the other hand, the energy of the progressive motion can just as well be converted into electricity as into heat, and therefore the assumption is justified that meteors represent an electrical and at the same time a glow-light phenomenon.

The tails of comets, too, which extend over many million miles are formed, according to Zöllner's view, by electrical processes which are caused by the action of the sun. If a comet, which is said to be a formation of fluid meteor masses, comes near to the sun, evaporating and boiling processes take place on the side turned towards it, and a vapour mantle is formed, and at the same time, also, electricity is continuously given off. The formation of the tail of the comet in a direction away from the sun is explicable by the repulsion between the electrical solar atmosphere and the electricity of the same

kind in the vapour envelope. If the electricity of the vapour envelope of the comet should, for any reason, become of opposite sign, the tail must be turned towards the sun, which is also sometimes noticed. This ingenious theory, which Zöllner has applied to the individual phenomena which had hitherto been observed in comets, such as curvature of the tail, oscillatory motion of the efflux, multiplication of the vapour envelopes, &c., promises more success than all other hypotheses which have been advanced in this problematical sphere.

Conclusions from the Experiments.

Starting from the unitary view as to the nature of electricity, I have explained the phosphorescent actions of radiant electrode matter in the following manner. The extremely attenuated matter the æther, which fills the whole universe and transmits light and heat, surrounds the atoms and molecules of a body just as the atmosphere surrounds the earth. In the normal condition each body has a definite quantity of this continually moving matter. If it possesses more æther than it should have corresponding to the density of the same in our part of the universe, then it is positively electrical; on the other hand, negatively electrical when it contains less æther. Now, if the negatively electrical particles of the electrode strike the glass, then, besides the agitation of the corporeal molecules, there will be an equalization of the quantities of æther between the striking particles and the part struck, which equalization cannot take place without an agitation of the æther envelopes of the molecules. Each spot of the glass struck becomes the centre of waves of æther quite analogous to a calm surface of water, which, when struck by drops of rain, shows waves of water in the plane. In consequence of these waves of æther thus sent into the exhausted space the glass side becomes luminous with a phosphorescent light peculiar to it, which is different according to the composition of the glass, because the wave-motion, in consequence of the difference of the density of the æther, will also be different.

That, in the impact, part of the energy of the progressive motion of the infinitely small projectiles of electrode matter is

changed into vibratory motion of the molecules of the glass, that is into *heat*, is just as self-evident as the conversion of that energy into progressive motion of the movable fly-wheel which is struck by particles of the electrode.

I have further succeeded in completely explaining the action of a magnet on the kathode rays by means of *molecular electrical convection*, and in bringing under *one* point of view this phenomenon, as well as Plücker's "magnetic surfaces," Hittorf's spiral-like convolutions of the glow-light, and the triple surfaces observed by Reitlinger and Urbanitzky.

The complete agreement of the theoretical results of molecular electrical convection with all the phenomena which have up to the present been observed, justifies the conclusion that the assumption as to the nature of radiant electrode matter, which serves as the starting-point of that explanation, is correct.

According to the dualistic view it is supposed that, in a conductor transmitting an electrical current, two equal quantities of dissimilar electricities are flowing in opposite directions. From Rowland's experiments on the transport of electricity by conductors and the views advanced in this communication on molecular electrical convection, it follows that even the motion of *a single* electricity in the sense of the unitary hypothesis exerts the same action on a magnetic needle as an electrical current flowing in a conductor at rest. But what appears to speak especially for the unitary view is the fact, which has long been known, that the electrical current only detaches particles *mechanically* from *one* pole.

If, for instance, we wish to assume that only that motion which manifests itself as negative electricity can separate the particles, we find another fact, that the current from the positive pole can detach the particles, as is the case with the electrical arc-lamp, in which the particles are transferred from the positive to the negative carbon point.

On the supposition that the electrical current is a real flowing of the æther, the facts alluded to can be easily explained.

I will here meet an objection which might possibly be raised against the æther theory of the electrical current, viz. that the mechanical action of the latter can be considerable, whilst the mass of the æther is infinitely small. According to

the calculation of Mr. P. Glan, the æther in a certain space (*e.g.* 1 c.c.) has very probably more mass than the hundred billionth part of the same space if it were filled with hydrogen of normal density. The highest limiting value given by Sir W. Thomson for the density of the æther is 7400 times larger*.

The mechanical action of masses in motion depends upon the *vis viva*—mv^2; it is greater the greater the mass or the square of the velocity of motion. We could thus explain the great mechanical actions of the electrical current, either by the great velocity of a small mass of moving æther, or, conversely, by a large mass of æther moving at a small velocity. The latter, however, appears to be the case, and the mechanical disruption of a particle of the electrode by the electrical current would thus be owing to the transference of a very large quantity of æther, which flows through the conductor with a small velocity.

It may further be remarked here that Wheatstone's experiments on the non-simultaneity of the sparks at different breaks in the circuit do not give any solution as to the *velocity of the current.* On the æther theory of the electrical current these experiments would only show that an excess or deficiency of æther, a condensation or rarefaction of the same, which is formed at one point of the conductor, is transferred at a very high velocity. It was, *à priori*, to be expected from the wave-theory that this velocity "*of the diffusion of the current*," as W. Weber † calls it, would be of the same order as the velocity of the propagation of light; and this is confirmed by Wheatstone's‡ experiment.

Whilst the *velocity of propagation of motion* from particle to particle is very great, the special motion of these particles—the *current velocity*—is very small, and is, according to Weber, 0·5 millim. in a second for a moist conductor (water).

Weber finds that in a current the intensity of which, according to *electrolytic* measurement, is $=1$, a quantity of positive electricity equal to $106\frac{2}{3} \times 155370 \times 10^6$ units

* Wiedemann's *Annalen*, vii. p. 658.

† *Electrodynamische Maassbestimmungen*, Abhandl. 2, p. 299.

‡ Ditto. Treatise 4, p. 281.

passes in one second in one direction through the section of the conductor, in conjunction with $\frac{1}{9}$ mgm. of hydrogen, and an equal amount of negative electricity in the opposite direction together with $\frac{8}{9}$ mgm. of oxygen.

Hence it follows that $106\frac{2}{3} \times 155370 \times 10^6$ units of positive and just as many of negative electricity must be contained in 1 mgm. of water; these, however, only progress, together with their ponderable carriers, with the velocity alluded to (0·5 mm. in a second) if the section of the moist conductor is only a square millimetre.

On this supposition it can no longer appear strange that an exceedingly attenuated matter like the æther can, nevertheless, cause an extremely violent action, which can put incomparably larger molecules of a body into a motion of heat, and even detach them from the body and throw them off with a very considerable velocity. It is evident, from the nature of the case, that this detachment of particles will only take place at the point where the current is emitted, which, however, does not imply that at the opposite pole, in consequence of another cause—possibly strong heating—detachment of ponderable matter could not take place.

Besides this the particles of æther will rub against one another in the spaces between the molecules of ponderable matter, and transmit part of the energy of their motion to the molecules of the body, causing in the latter vibratory motions like the vibrations of the strings of an æolian harp by the progressive motion of currents of air.

If we wished to draw conclusions as to the direction of the hypothetical æther current from the direction of motion of the detached particles of the electrode, we must suppose that in induction-currents in rarefied spaces it proceeds from the *negative* to the *positive* pole; on the other hand, in galvanic currents in the *opposite* direction, because in the latter a transference of the detached particles takes place from the positive to the negative pole, when the electrodes are of the same metal and of approximately equal shape.

Resting on these two facts, we have at the point of emission of the galvanic current free positive and of the induction-current free negative tension.

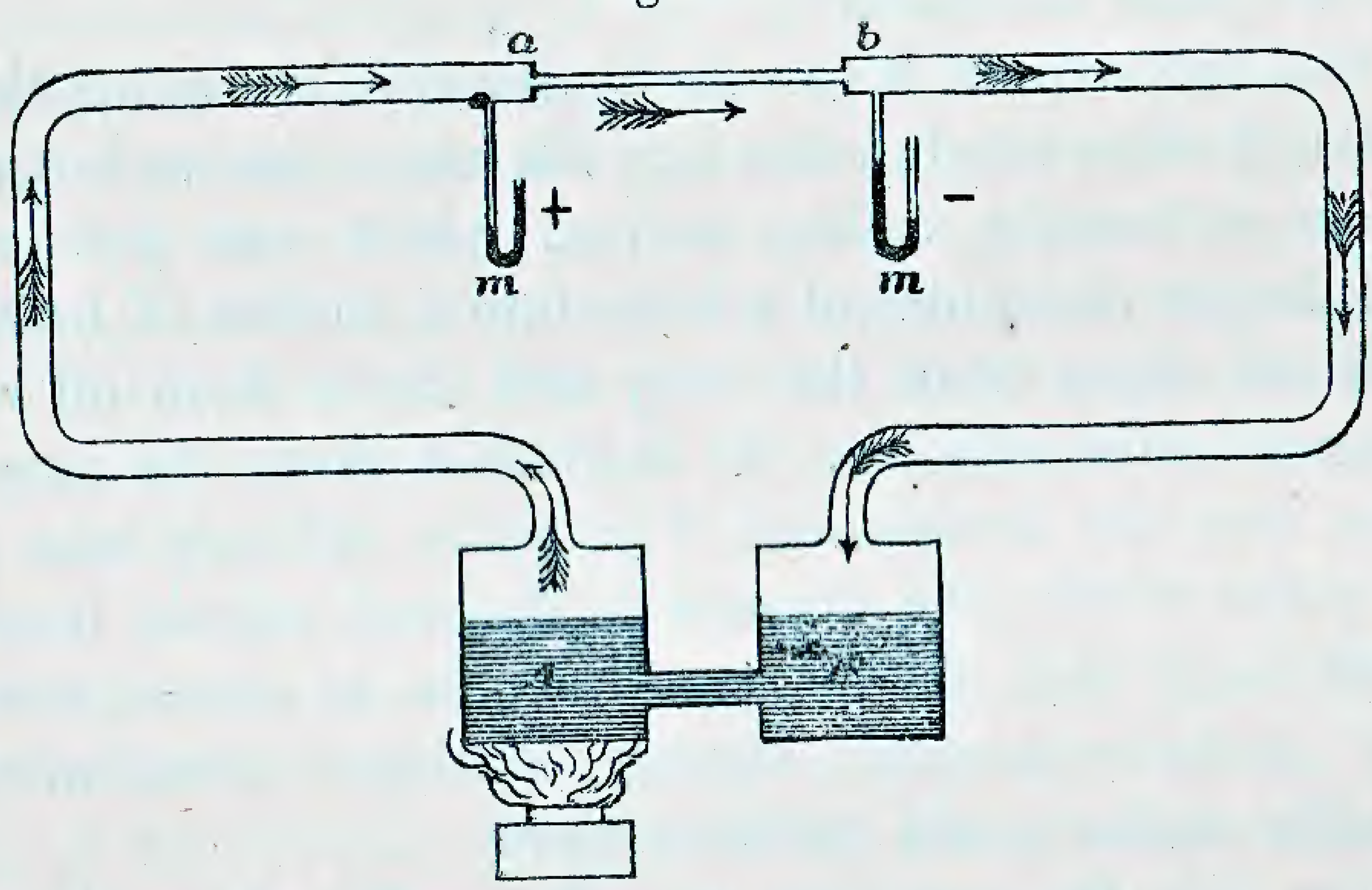
We can therefore put the following question: Can an

inversion of the tensions take place at the point where the æther current is emitted, and what is the cause of it?

The explanation is given without recourse to any hypothesis, simply from the well-known laws of convection, which have been experimentally proved, which all fluids must follow and therefore the æther also.

These laws may be elucidated first with a ponderable fluid, for example superheated steam. Fig. 63 represents a

Fig. 63.



system of tubes, which is in connexion with two communicating vessels filled with water. Steam is generated in A and superheated; it flows through a system of tubes, into which a capillary $a\,b$ is introduced, and which is provided with two open manometers, m, and condenses in B.

It is easily seen that the manometer at a will show a packing, and at b a rarefaction of the steam. The excess of steam shall be represented by $+$, and the deficit by $-$.

If a vessel of greater section than that of the conducting tubes be introduced instead of the capillary, a rarefaction $(-)$ will be formed at the point of emergence from, and a compression $(+)$ at the point of entrance into, the system of tubes.

The current of æther continuously generated in a battery by chemical forces will in a manner quite analogous be compressed by the greater resistance on its entrance into a conductor, and on its exit from it will be rarefied. At the former point an excess, at the latter a deficiency, of æther or positive and negative free tension will be produced. This condition of

things takes place in the electrical arc-lamp, in which the distance of air between the carbon points offers a considerable resistance to the galvanic current.

The layer of air in evacuated tubes is certainly much greater in comparison to the distance of air between the carbon points, but the tension of induction-currents also is far greater than that of galvanic currents. The layer of air in the evacuated tube offers a small resistance to the induction-current, and therefore the negative pole is at the point of entrance into the layer of air.

This explanation of the inversion of the tensions of electricity certainly in simplicity leaves scarcely anything to be wished for, and the analogy between the phenomena of the convection of liquids and those of the electrical current is so great that it would not be easily possible to overlook it. I do not know also how the fact of the inversion of the poles could be better and more simply explained according to the now dominant dualistic theory.

Another conclusion can be drawn from the hypothesis advanced as to the nature of the electrical current which is in best accordance with observation. If a battery is closed by a wire, it opposes a resistance to the æther which is striving to equalize itself, and therefore a partial packing of the æther occurs in the wire which, beginning at the positive pole, decreases towards the middle of the wire up to a point at which the free tension is zero. On the other side of this boundary a deficiency of æther, that is negative free tension, manifests itself in a continuously increasing manner quite analogous to the fall in pressure in flowing liquids. Whilst this distribution of free tensions in the conducting wire is self-evident according to the æther theory, the prevalent dualistic theory offers no answer to the question why the free electricities in the conducting wire do not combine with one another as they otherwise do in an extraordinarily short space of time.

On the other hand, it is evident that the case will also be the same in evacuated tubes. A deficiency of æther, that is a negative free tension, is formed at the point where the current of æther enters the column of gas, whereas at the positive pole an accumulation of the æther, positive free

tension, occurs. There must, therefore, be one point between both poles which would act neither positively nor negatively towards other bodies, and this *indifferent* place would fit very well for the *dark space* between the positive brush of light and the glow-light*.

The facts proved by direct experiment by De la Rive verify this assumption, viz.: that the dark space is *colder* than the rest of the path of discharge, and that a distinctive *flowing of electricity cannot be detected* in it†.

The above assumption is also in best agreement with the results of the electroscopic investigations of evacuated tubes which are traversed by an induction-current.

If a tube traversed by an induction-current and insulated at both electrodes be connected to an electroscope by means of a strip of tin-foil and tested at various points, it will be found, as Prof. G. Wiedemann has proved, that the tube is negatively electrical in the neighbourhood of the negative, and positively electrical in the neighbourhood of the positive pole. Both electrical free tensions decrease towards the dark space, and are here almost zero. The small tension of the glass tube about the dark space is sufficiently explained on the assumption that the propagation of electricity also takes place through the glass, and that in this conductor the indifferent zone can occur at a different point to that in the inner column of gas. This can be verified by charging only one electrode, the other being put to earth. The tube appears indifferent at the emergent electrode, and is in its whole length similarly electrical to the charged electrode‡.

If the explanation of the dark space given is correct, the stratified structure of the positive brush-light can be explained as follows. It is probable that the dark space is only the first dark stratum, and that all dark parts in the positive brush of light are just as many indifferent points or strata of no tension, the origin of which could be explained mechanically. The intermittent discharges of the particles detached from the electrode will cause compressions and

* As distinguished from the dark space immediately at the negative electrode.

† Poggendorff's *Annalen*, clviii. p. 271.

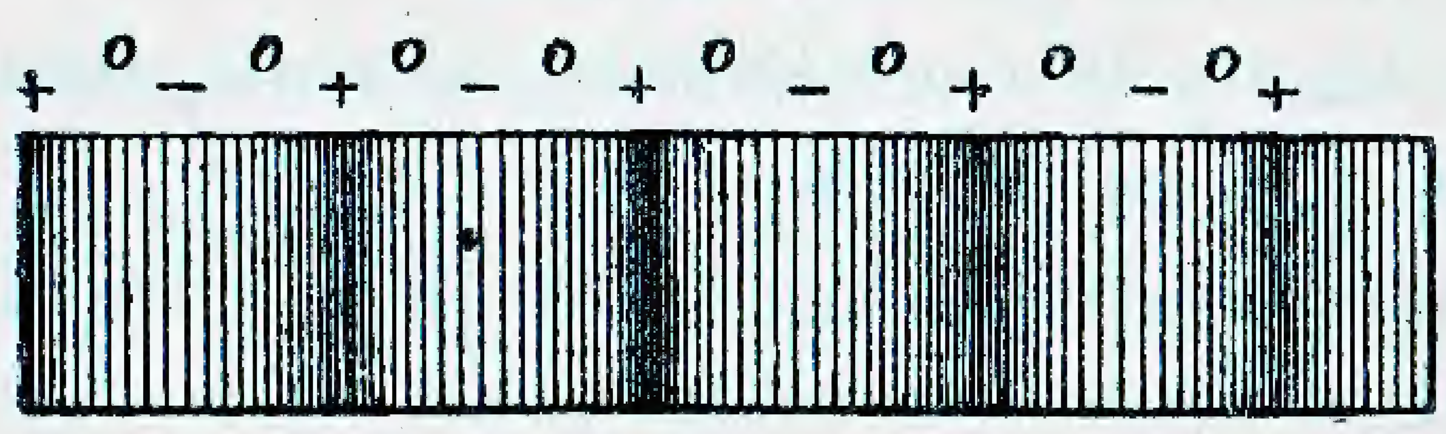
‡ Poggendorff's *Annalen*, *tom. cit.* p. 59.

rarefactions in the enclosed column of air, which will take place the more regularly, the more regular is the vibration of the contact-breaker. The number of these waves will depend upon the nature of the gas and the form of the vessel and of the electrodes.

Since, moreover, the rarefied gas offers a smaller resistance to the discharges than the compressed one does, positive and negative tensions will be formed at the points of ingress to and egress from the compressions.

At the points of greatest compression and of greatest rarefaction, free positive and negative tensions will respectively result, as represented in the drawing (fig. 64). The indifferent places (0) will lie between them.

Fig. 64.



That the blue colour of the glow-light does not appear alternately in the strata is to be explained by the fact that the particles of the electrode are here wanting. I only noticed once a very distinct blue surface about 1 millim. thick of the *first* bright whitish stratum on the side facing the negative electrode. Ciamician, who lately has experimented much with spectrum tubes, is said to have also seen such superficial blue-coloured strata.

The compressions and rarefactions of the column of air will certainly be formed throughout the whole tube if the gas is everywhere in an equal state of motion. That this formation of strata in the glow-light must be modified by the electrode particles being violently thrown about, is to be expected.

In the same way no formation of stratification is to be expected with a constant discharge of the electrical current.

If the tube be more strongly exhausted the wave-lengths must increase, but at the same time the number of waves decrease because the glow-light extends further the smaller the resistance to the motion of the residual gas. If the glow-light be repelled by means of a magnet in the neighbourhood

of the negative electrode, the strata can be formed in the space free of glow-light. The strata disappear entirely if the glow-light extends to the positive electrode.

Many investigators have been occupied with the explanation of the formation of strata; it would, however, exceed the limits of this communication were I to submit to a criticism the views hitherto advanced on this subject.

As far as I can survey the wide field of the conduction of electricity in rarefied gases, I cannot put aside my conviction that only the assumption of a single movable fluid can explain in an unconstrained manner those electrical phenomena which have hitherto remained an unsolved riddle for the dualistic theory. And if, perhaps, the explanation given may appear very simple, it is, on the other hand, clear and free from new hypotheses and mysticisms.

The æther theory of electricity has become, especially in the last ten years, the subject of a deeper study. Franklin, as is already well known, tried to explain the electrical phenomena known at his time on the assumption of a single electrical fluid. He did not, however, succeed in accounting for the repulsion of two negatively electrical bodies, and Franklin's view and that of the "Unitaries" had to give place to that of the "Dualists," who would explain the electrical phenomena with two electricities. Only latterly has the unitary idea been again taken up by important scientific men, and further extended with success.

I must here, first of all, refer to a meritorious man, the astronomer Angelo Secchi, who, in the year 1863 in his book 'The Unity of the Forces of Nature,' clearly expressed the idea that the electrical current is an actual flowing of the æther, and explained, with the help of the experimentally proved laws of hydrodynamics hitherto known, most of the electrostatic and electrodynamic phenomena in a simple and intelligible manner.

Edlund, 1871*, afterwards starting from the assumption of a single fluid, has deduced the empirical formulæ given by Ampère for the mutual action of two elements of current which govern the laws of all electrodynamic phenomena. He relies thereby upon two fundamental principles, viz. :—

* Poggendorff's *Annalen*, Suppl. vol. vi. pp. 95, 241.

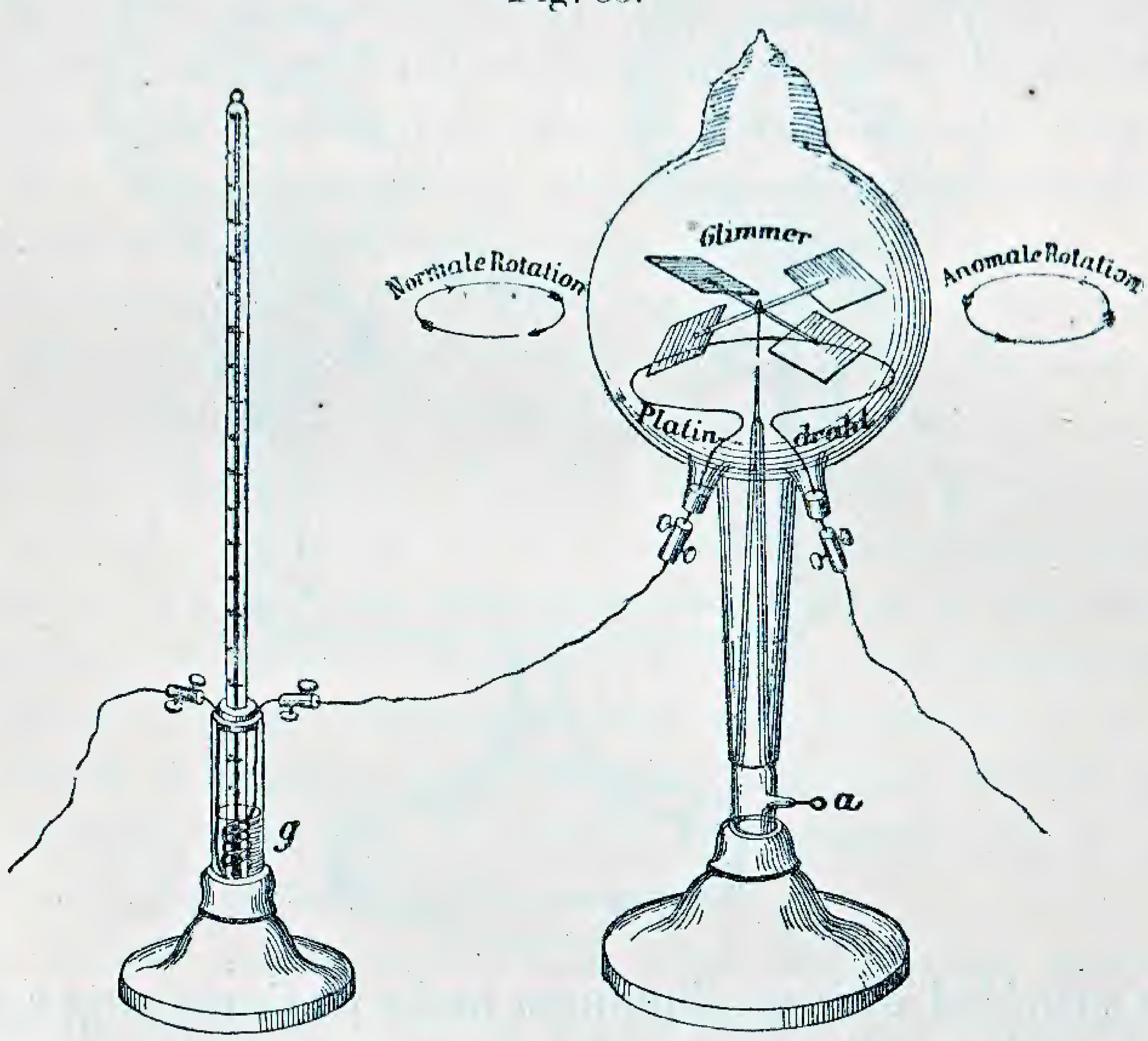
1. On the principle of Archimedes, the application of which to phenomena of this kind appears to be incontestable, and has been verified experimentally by the diamagnetic experiments of Plücker. 2. On the principle that everything which takes place or happens in external nature requires a certain time. Besides this Edlund succeeded in accounting for most of the phenomena of the galvanic current by the æther theory.

Though I cannot disguise to myself the conviction that the æther theory has only few and timorous supporters, I thought that publicity ought to be given, not only to the experimental results of my investigations on radiant electrode matter, but also to the conclusions which I infer from them.

Contribution to the Explanation of Zöllner's Radiometer.

F. Zöllner describes, in the third communication of his *Untersuchungen über die Bewegung strahlender und bestrahlter*

Fig. 65.



*Körper,** an ingeniously constructed radiometer, the wonderful phenomena of motion of which have not hitherto been

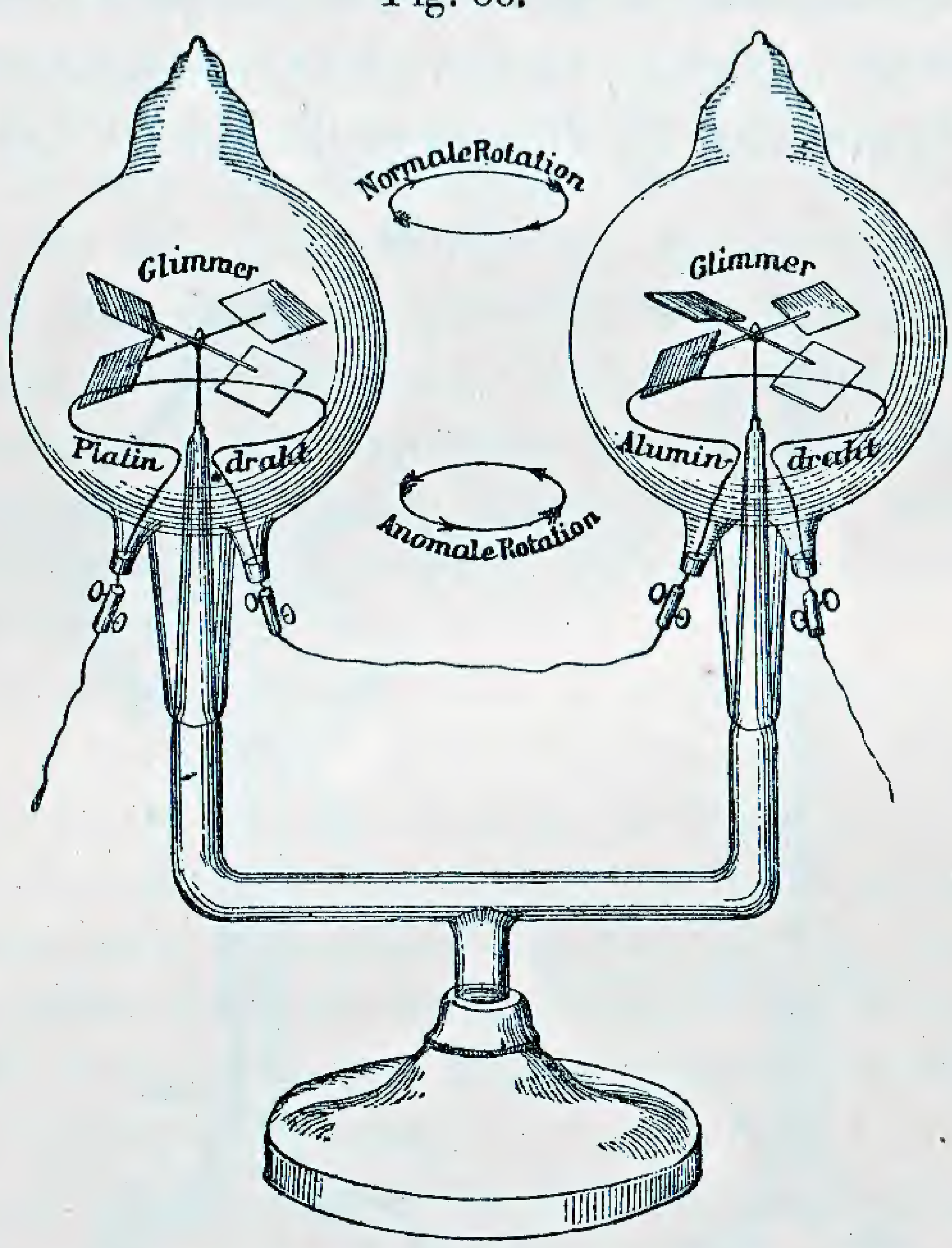
* Poggendorff's *Annalen,* clx. p. 460.

explained. The apparatus consists of a movable cross with unblackened mica plates which, as represented in fig. 65, are obliquely inclined to the horizon. Below the cross is a ring of platinum wire lying horizontally, and its ends fused into the glass in order to transmit a galvanic current.

The rise in temperature of the platinum wire was approximately determined by a thermometer, *g*, which was divided into fifths of a degree, the bulb being surrounded by a platinum wire of the same thickness as that in the radiometer, in a closely-fitting spiral of several turns. The thermometer was then placed in a vessel containing a non-conducting liquid, such as copal varnish, which surrounded the spiral of wire (fig. 65).

The following phenomena were observed in an apparatus with two communicating radiometer-bulbs (fig. 66), which

Fig. 66.



were provided with an aluminum and a platinum ring respectively, with a galvanic rise of temperature of the wire of at most 10° C., and at different pressures of the gas in the interior of the bulbs.

1. At an ordinary barometric pressure of 760 mm. a

normal rotation took place, that is, such as could be explained by a heated current of air ascending from the wire.

2. On a continuous decrease of the pressure a turning-point occurred at about 100 mm., when the rotation decreased at this pressure with diminishing velocity to a standstill.

3. At lower pressures than 10 mm. an *abnormal* rotation in the *opposite* direction took place, that is, such a one as could be explained by an *absorption of gas* by the heated wires both of aluminum and of platinum.

4. This abnormal rotation remained unchanged down to pressures which could no longer be determined barometrically, and at which, as it *appeared*, an ordinary radiometer placed simultaneously in connexion with the pump had already passed the point of its greatest sensitiveness.

5. On continued rarefaction the normal rotation again commenced *almost* suddenly, but with such a velocity that it was no longer possible to distinguish the individual parts of the rotating cross. Zöllner had never observed a velocity of rotation even approaching this with the most delicate radiometers when exposed to a most powerful solar radiation. The galvanic heating of the wire need only be 2 to 3°. The turning-point seems to occur approximately simultaneously with the platinum and aluminum wires.

It is self-evident that all these experiments succeed as well when the rings are placed *above* instead of *below* the movable cross, only the direction of rotation is always reversed.

If the vessel be fused off with the enclosed gases at this small pressure, a normal rotation similarly takes place under the same conditions on the galvanic heating of the wires. The velocity of rotation decreases, however, continually until after 8 to 10 days ; a stoppage occurs even on heating to a red heat, which is changed later into an abnormal rotation, and these changes can only be caused by a gradual increase of pressure in the interior of the vessel.

Still another experiment which Prof. Zöllner has made is interesting, by simply placing the radiometer in full sunlight. A *normal* rotation took place even if the pressure had so far increased that on galvanic heating of the wire an *abnormal* rotation occurred.

Prof. Zöllner deduced from these experiments that the

galvanic current acts on the mica plate not only by the heating caused by it in the wire, but that a specific action on the surrounding gaseous medium must be ascribed to the current, which is of opposite action to that caused by the rise in temperature. This action *could*, according to Zöllner, be explained by a resorption of the surrounding gas.

The following observation is advanced in support of the existence of such a process of absorption. The double apparatus represented in fig. 66 was placed between the double windows of a room after having been closed at a rarefaction corresponding to a *normal* rotation. Whereas for some days after closing a decrease in the normal velocity of rotation had commenced, a slow rotation in the abnormal direction was noticed one evening in the moonlight. This rotation was also noticed at night without moonlight during a period of time of four weeks. By day, too, with a thickly covered sky the same rotation took place, whereas rest occurred on bright illumination, which on irradiation by the sun was transformed into a *normal* rotation. It lost, however, this property by degrees.

Another fact is shortly alluded to in the paper. Prof. Zöllner surmised that the phenomenon was in connexion with an irradiation towards space, and opened therefore the outer window in order to increase this emission of rays, whilst the inner one was closed again. The action which took place was opposite to that expected; the motion ceased completely after the expiration of half a minute. As soon, however, as the outer window was closed again the abnormal rotation recommenced. Zöllner often repeated this experiment with equal success, and showed it to his friends.

During a lecture I was giving to a scientific society on "Radiant Electrode Matter," I noticed that the wheel in a Zöllner's radiometer of the form represented in fig. 65 turned in an *abnormal* direction at a degree of rarefaction at which *normal* rotation took place in consequence of galvanic heating or of emission of radiant electrode matter, for which purpose another electrode was fused into the radiometer at *a*, fig. 65. I thought at once of the moonlight in Zöllner's experiment, and it appeared to me very probable that the cause of this problematical motion might be due to

the radiation from a series of gas-burners, which were placed at a distance of about 3 metres from the lecture-table, almost at the ceiling, in the lecture-hall.

I surmised that an illumination of the radiometer from below would cause a motion in the opposite direction. The experiment was afterwards tried with a batswing burner, and my supposition verified. If the flame was vertically or obliquely above the apparatus, the rotation took place in an *abnormal* direction and was changed into an oppositely *normal* direction if the flame was placed below the apparatus.

If, further, the vessel of the apparatus was covered with blotting-paper soaked with ether and was still warmed below the cross by touching with the hand, a very rapid rotation took place in an *abnormal* direction. An opposite rotation took place on cooling the lower and heating the upper part of the glass vessel.

On one forenoon I noticed with the same apparatus a rotation in an *abnormal* direction, although no sun's rays penetrated into the room, and the apparatus only stood in diffused light in the neighbourhood of the window. In the afternoon it came to rest.

It might have been conjectured that the cause of this motion was the radiation from the ceiling of the room, which was relatively warmer than the ground in the forenoon than in the afternoon.

I made an experiment with hot copper plates, which I placed horizontally at a distance of about a metre above and below the radiometer. The result showed that heat and light rays cause the *same* rotation, an *abnormal* by irradiation of the vessel from above, and a *normal* by irradiation from below.

I repeated also Zöllner's experiment by placing the radiometer directly in the sunlight. The cross revolved in a *normal* direction. However, on allowing a pencil of solar rays, which entered the workroom through a hole of about 7 cm. diameter, to fall on the radiometer from above, the cross rotated in an *abnormal* direction as with the gas-light and heat-rays, and returned to the *normal* direction as soon as the pencil of rays was turned on to the lower part of the apparatus by means of a mirror.

These, as well as the radiometric experiments made by

Prof. Zöllner at a greater rarefaction (0·02 millim. mercury pressure), can be explained in the following way:—

If the hot metallic plate, PP (fig. 67), be placed above the spherically-shaped apparatus, only the upper half of it is struck by heat-rays and heated. The sketch represents a section of the glass vessel in the vertical plane tangential to the platinum ring; *r r* is a piece of the platinum ring, and *m m* the section of the mica plate placed obliquely to that vertical plane.

The molecules of gas striking against the upper glass side leave it with a greater velocity, and convey by collisions a part of their kinetic energy to the vanes, *m m*, which, in consequence, will experience an excess of pressure normal to the surface. The vertical component of this pressure is neutralized by the point, whereas the second component parallel to the ring drives the vane in an *abnormal* direction, as is apparent from the sketch.

It is easily seen that, if the plate be placed below the apparatus, the small plates will experience an excess of pressure from below to above directed normally against the surface, and that therefore the motion must be reversed.

Fig. 67.

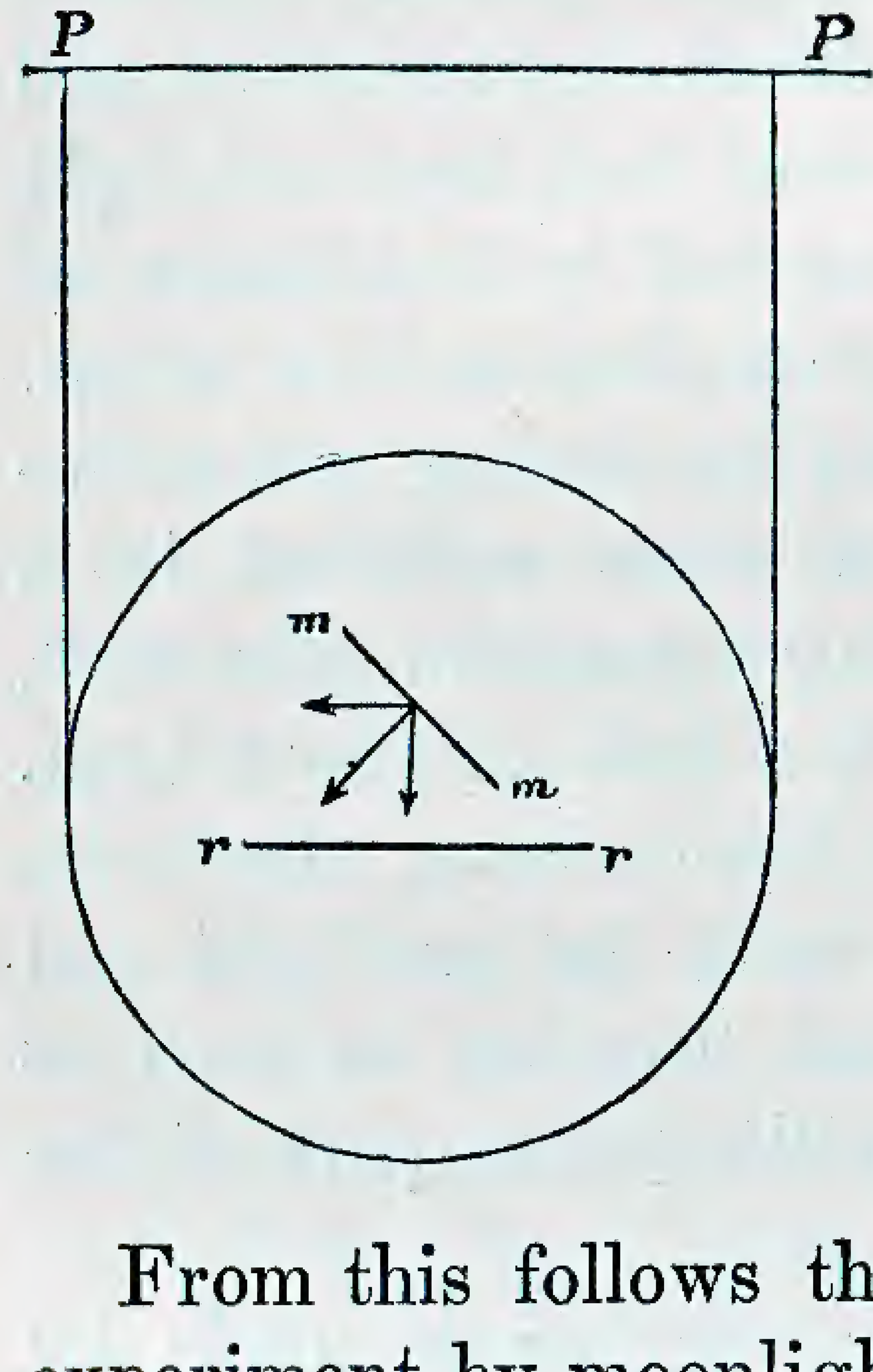
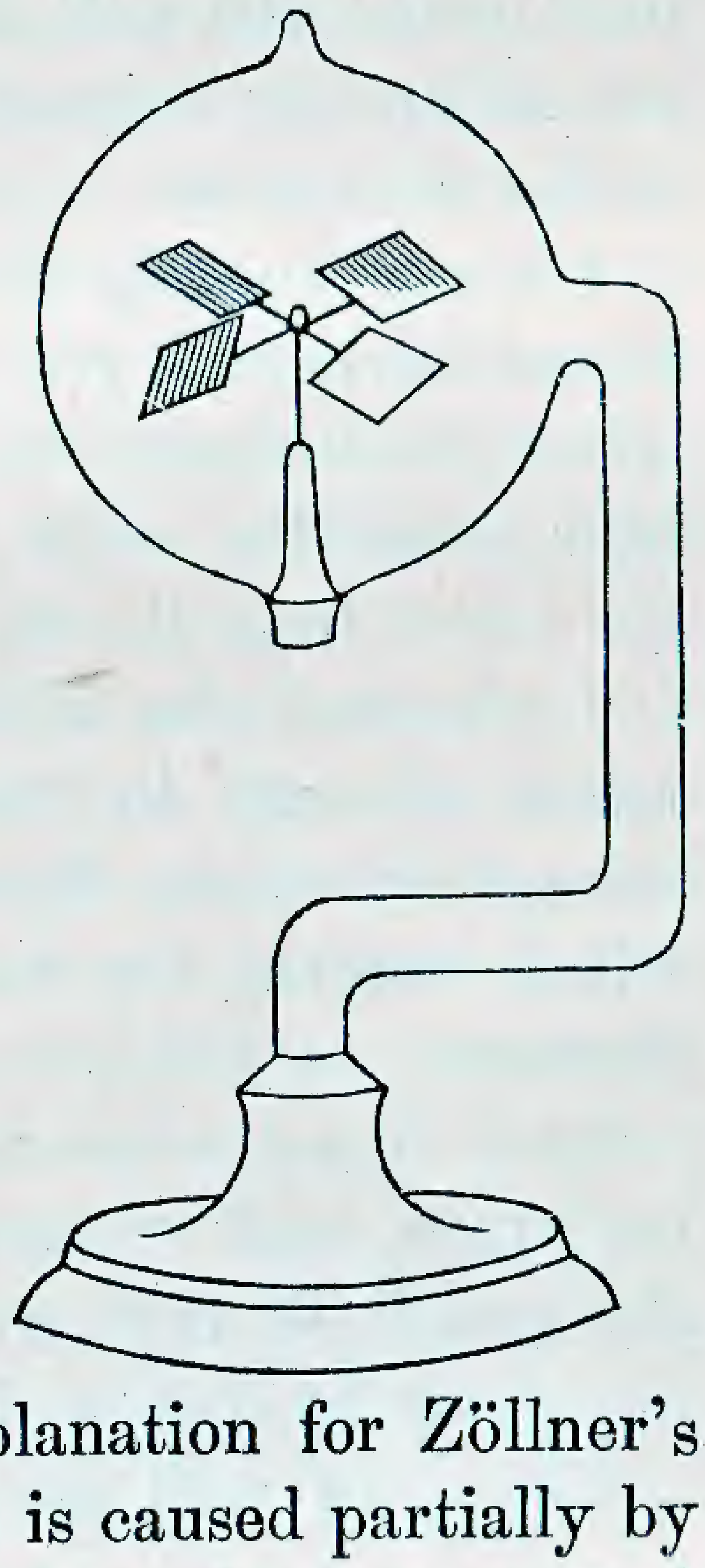


Fig. 68.



From this follows the following explanation for Zöllner's experiment by moonlight. The motion is caused partially by the faint moonlight, but *principally* by *heat* which is emitted

from the upper part of the double window more strongly than from the lower. With an open window the temperature has become equalized in the whole space of the double window, and a stoppage takes place in the motion. The stronger radiation of heat from *above* was the cause of the *abnormal* motion which was noticed by Prof. Zöllner also *without* moonlight and by me in the forenoon in a warmed room. In the afternoon the temperature had become equalized, and the small difference of temperature between the ceiling and the floor was not sufficient to overcome the resistances to motion. The wire ring is of secondary importance for this experiment; it will weaken or strengthen the motion according to whether the irradiation takes place from above or below. That these experiments must succeed also without the wire ring follows from the explanation given. I have made experiments of this kind with success, and indeed with the apparatus represented in fig. 68.

The cross rotates in an abnormal or normal direction, according as it is warmed by the hand either above or below.

If the apparatus be acted upon by luminous rays, and in such a manner that they fall upon it from above, the rays of light will pass through the glass sides and strike the upper surfaces of the mica plates, and since the latter conduct heat badly they will be warmer on the irradiated side than on that which is in shade. Hence from the reaction of the gas molecules there results a pressure directed perpendicular to the plates and downwards, which turns the plates in an abnormal direction. On illuminating the apparatus from below, the conditions and direction of rotation are reversed.

If the apparatus *without a wire ring* be placed in full sunlight, both actions are more or less in equilibrium, and even if the radiation from above be somewhat stronger, this small difference in the radiation is not sufficient to overcome the resistances to motion; such an apparatus must therefore *remain at rest* in full sunlight.

Prof. Zöllner has already made this experiment*. In the first communication of his investigations, in reference to an apparatus in which a disc of aluminum foil was placed below the cross instead of the platinum ring, he remarks as follows:

* Pogg. *Annalen*, clx. p. 166.

"The cross just described shows, when enclosed by itself in a glass vessel in the same way as the radiometer crosses, *no* rotatory motion, even in bright sunlight. If, however, a screen of bright aluminum foil be placed as near as possible beneath it, the cross rotates even with a heavily clouded sky almost as quickly as the most delicate radiometers I have hitherto seen. The direction of rotation corresponds to an emission from the metallic surface."

If a *wire ring* is situated below the cross it becomes warmed in full sunlight, the molecules of gas rebounding from it transmit part of their *vis viva* to the mica plates and cause a rotation in the *normal* direction.

I may here refer to another explanation of the phenomena of motion in Zöllner's radiometer where the platinum ring is *traversed by an electric current.*

Nobody will doubt that the motion in a normal direction at a full atmospheric pressure is caused by currents of air produced by the heated wire. On the other hand it appears to me that Zöllner's view of the possibility of explaining the abnormal motion at smaller pressures than 10 mm. by an absorption of hydrogen by the platinum ring has less probability from the fact that this inversion was also observed by Zöllner himself with an aluminum ring, which certainly will only absorb hydrogen to a proportionately very slight extent. Moreover this reabsorption, and therefore also the motion, must some time come to an end, which is not the case. I am also of opinion that one would rather expect the *heated* wire to *exude* and not absorb gases.

I should be inclined to look for the cause of this inversion in the dielectric polarization and electrification of the mica plates. The wire traversed by a current will possess free electricity on its surface, which acts inductively on the mica laminæ and makes the sides turned towards it electrical.

I can, however, advance nothing with certainty as to how a pressure directed normally against the surface of the plate results from the electrical action of the platinum ring, which causes it to rotate in an abnormal direction, but I am none the less decidedly convinced of the electrical origin of this motion. The following experiment appears to me to point to this:—If one pole of the induction apparatus be connected with the platinum ring and the other be put to earth, and if

the pressure in the radiometer is so great that by using the galvanic current an abnormal rotation would take place, the cross likewise rotates in an abnormal direction whether the positive or negative pole is put to earth.

If the action of the dielectric polarization is weaker than the action of the currents of air opposite to it, a normal rotation takes place according to Zöllner's statement from 760 to 10 mm.

If the galvanic current be broken whilst the radiometer is rotating in an abnormal direction, an inversion and rotation takes place in a *normal* direction. This rotation is caused by currents of air, and only lasts a short time because the wire rapidly cools down.

At high degrees of rarefaction a new cause of motion is superadded, viz. radiant heat, the action of which is also opposite to that of dielectric polarization. In consequence of greater rarefaction the wire becomes red hot, the intensity of the current smaller, and therefore also the mica plates less strongly electrical. The radiant heat of the platinum ring warms the mica plates on the sides facing it, and the reaction of the molecules rebounding with greater velocity from the mica plates, tends to turn the latter in a normal direction. As, moreover, heated gaseous molecules, that is those which are endowed with great velocities, issue from the platinum ring and transmit part of their *vis viva* to the vanes by collisions in the same sense, the *normal* rotation will be also thereby strengthened.

We can thus imagine a three-fold cause of the phenomena of motion in Zöllner's radiometer. Currents of air and thermal radiation tend to turn the plates in a *normal* and the action of the dielectric polarization in an *abnormal* direction. The currents of air decrease with the rarefaction, the action of the dielectric polarization predominates, and the first inversion takes place at 10 millim. On continued rarefaction the heating of the wire increases in consequence of the smaller thermal conductivity of the gas, and the intensity of the current decreases as well as the electrification of the mica plates, and since, moreover, the thermal radiation increases simultaneously, the action of the latter will predominate at a certain pressure, about 0·02 mm., and after a second inversion a *normal* rotation takes place.

If we could succeed in eliminating one action, *e.g.* that of heat, by replacing the platinum ring by a thick copper one, it is to be expected that the first inversion would take place at higher pressures than 10 mm., and that the second would perhaps not take place at all.

If this experiment, which I am thinking of next carrying out, is verified experimentally, it would be an indirect proof of the correctness of the explanation given by the electrification of the mica plates.

Appendix.

Whilst reading the proofs of my communication, "Contributions to the Explanation of Zöllner's Radiometer," I heard of a new paper of Prof. Zöllner, entitled *Das Scalen-Photometer* (Leipsic, 1879), which contains an answer to the objection I raised* to his theory of emission. Prof. Zöllner remarks in reference to this, "The presence of a small residue of gas, especially of oxygen, may very well favour a separation of the electrical particles by a sort of catalytic action, and thus cause a maximum effect of rotation at a certain degree of rarefaction."

With regard to this explanation I take the liberty of observing that I cannot feel convinced by it for this reason, that such catalytic actions as Prof. Zöllner assumes have not yet been *experimentally* demonstrated, and therefore possibly also do not exist. Hence a still more powerful support will be needed in order that the emission theory may hold its ground with the simple method of explanation by the kinetic theory of gases.

It may, too, be remarked that an experiment with the induction-current is given in the paper referred to, p. 59, which I have described on p. 321. Starting from this experiment Prof. Zöllner explains the *abnormal* rotation (by using an electrical current and a pressure of 10 to 0·02 mm.) as due to the existence of a *double current* of molecules of gas moving

* "Ueber das Radiometer." *Sitzungsberichte der Wiener Akademie*, vol. lxxx. 1879.

electrically, and indeed after the analogy of the double current of solid particles which are suspended in a liquid transmitting an electrical current, observed by Faraday, Armstrong, and Quincke. As to the mode of action of this double current Prof. Zöllner writes as follows :—

"If we therefore assume a similar relation between the large and small molecules in the rarefied spaces of the radiometer, which, however, are *always filled with mercury vapour*, and consider that at high densities of the vapours and gases the larger molecules will predominate, then the direction in which the mica cross *rotates* would really show the direction of the *ever present double current* of molecules of gas according to the degree of rarefaction."

Prof. Zöllner's view coincides with my own supposition as to the nature of the force which causes the abnormal rotation, but whilst I have openly confessed that I am still in doubt as to the *mode of action* of this force, Prof. Zöllner attempts an explanation which, even if supported by analogies, must first earn for itself recognition by further experiments.

Professor Gintl's Views on Radiant Matter.

In January 1880 the chemist Prof. Wilhelm Friedrich Gintl, of Prague, published a paper, "*Studien über Crookes strahlende Materie und die mechanische Theorie der Electricität,*" in which he tries to answer the question from a purely critical point of view as to whether the assumption of the existence of a particular state of aggregation is really justified by the experiments of Mr. Crookes. This pamphlet, which was published by the author himself, was overlooked in the 1883 edition of the present collection of my papers, published in the Memoirs of the Royal Academy of Science of Vienna, because it had not come under my notice at that time. In taking the liberty, therefore, of calling the reader's attention to this interesting research, I need only say that Prof. Gintl, reasoning from a critical investigation of the phenomena described by Mr. Crookes in his lecture on "Radiant Matter," arrives at the conclusion that Mr. Crookes's views are not borne out by several phenomena observed by him, and that for the explanation of the phenomena in question

there is no necessity for the assumption of a hypothesis, so far removed from what is known, as that which he advances, viz. the fourth state of matter.

Prof. Gintl arrives further at the conclusion that "particles are propelled from the surface of the substance of the negative pole which move with a velocity corresponding to the resultants of those antagonistic forces in a parallel and rectilinear direction from the pole and retain their velocity as also their direction of motion so long as they do not encounter obstacles which influence their motion."

In reference to the cause of the detachment of the particles from the negative pole, Prof. Gintl makes the following remarks:—"Let us consider only the negative pole of the conductor at which the phenomena of radiant matter take their origin at the moment when the conductor is traversed by a current. Let us start with the known behaviour of such a pole charged with electricity of a certain tension towards other bodies brought near to it. We recognize then, without any difficulty, that the actual repellent action, which is exerted by such a pole on bodies brought into its neighbourhood, as soon as the latter have acquired a similarly electrical state, must without doubt manifest itself to a still higher degree in the case of those molecules or groups of molecules which form the outer layers of the substance of the pole. Since the amount of this repulsion increases with increasing tension of the electricity, we may conclude that at a certain degree of this tension the repulsion of the surface molecules can become so great that it exceeds the amount of their attraction by the other molecules of the substance. In this case the molecules or groups of molecules forming the peripheral layers will detach themselves from the rest of the mass, and move in a rectilinear and parallel direction away from the pole." The author leaves it still an open question as to whether the detached particles, the disengagement of which has frequently been observed, are to be considered as isolated molecules or groups of molecules.

Prof. Gintl has, however, strange to say, not drawn the necessarily evident inference from this perfectly correct view as to the cause of the disintegration of the negative electrode, that the particles detached from the negative pole

must be "similarly," that is to say, *negatively* electrical; on the contrary, he thus expresses himself in reference to it:—

"As regards the deflection by a magnet, the question next arises whether the continuance of a change of state in the particles of the so-called radiant matter proceeding rectilinearly is to be considered in such a manner as that the latter, as homogeneous electrified bodies, form as it were a flying electrical current, an *assumption which we shall scarcely be justified in admitting in consideration of the logical consequences thereby involved.*"

The author of the research on Radiant Matter gives some intimations as to how the deflecting action of a magnet on radiant matter, the mutual repulsion of two brushes of the same, and the convergence of the rays which proceed from a cup-shaped electrode can be explained, to which, however, with reference to the facts advanced in my paper, I cannot assent. To explain in an unconstrained manner all electrical phenomena in vacuum tubes, it must be assumed unconditionally that the particles discharged from the negative electrode are charged with negative statical electricity, that thus in a vacuum tube dynamical is changed into statical electricity, and that the latter is taken up by the particles from the electrode, carried further away and given up partly to the glass sides, partly to the positive electrode, to be here changed back again into dynamical electricity.

Prague, February, 1888.